UNCLASSIFIED

AD NUMBER
AD835392
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Critical Technology; MAY 1968. Other requests shall be referred to Army Materiel Command, ATTN: AMCRD-T, Washington, DC 20315. This document contains export-controlled technical data.**
AUTHORITY
AMC ltr dtd 22 Jul 1971

THIS PAGE IS UNCLASSIFIED

TECHNICAL REPORT NO. 3-726

MOBILITY ENVIRONMENTAL RESEARCH STUDY A QUANTITATIVE METHOD FOR DESCRIBING TERRAIN FOR GROUND MOBILITY

Volume I

SUMMARY

by

J. H. Shamburger

W. E. Grabau

May 1968

Sponsored by

Advanced Research Projects Agency
Directorate of Remote Area Conflict

Service Agency

U. S. Army Materiel Command

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

63

Destroy this report when no longer needed. Do not return it to the originator.

The findings in this report are not to be construed as an official Department of the Army position, unless so designated by other authorized documents.

TECHNICAL REPORT NO. 3-726

MOBILITY ENVIRONMENTAL RESEARCH STUDY A QUANTITATIVE METHOD FOR DESCRIBING TERRAIN FOR GROUND MOBILITY

Volume I

SUMMARY

by

J. H. Shamburger

W. E. Grabau

May 1968

Sponsored by

Advanced Research Projects Agency
Directorate of Remote Area Conflict
Order No. 400

Service Agency

U. S. Army Materiel Command

Conducted by

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

ARMY-MRC VICKSBURG, MISS.

FOREWORD

The study reported herein was performed by the U. S. Army Engineer Waterways Experiment Station (WES) for the Office, Secretary of Defense (OSD), Advanced Research Projects Agency (ARPA). This report describes portions of two tasks of the overall Mobility Environmental Research Study (MERS) sponsored by OSD/ARPA for which the WES was the prime contractor and the U. S. Army Materiel Command was the service agent. The broad mission of Project MERS is to determine the effects of the various features of the physical environment on the performance of cross-country, ground-contact vehicles, and to provide therefrom data that can be used to improve both the design and employment of such vehicles. A condition of the project is that the data be interpretable in terms of vehicle requirements for Southeast Asia. The funds employed for this study were allocated to WES through AMC under ARPA Order No. 400. The study was performed during the period June 1964-November 1965 under the general guidance and supervision of the MERS Branch of the WES, the staff element of WES responsible for the technical management and direction of the MERS program.

This volume is one of an eight-volume report entitled A Quantitative Method for Describing Terrain for Ground Mobility. These volumes are:

I: Summary
II: Surface Composition
III: Surface Geometry
IV: Vegetation
V: Hydrologic Geometry
VI: Selected Air-Photo Patterns of Terrain Features
VII: Development of Factor-Complex Maps for Ground Mobility
VIII: Terrain Factor-Family Maps of Selected Areas

Government agencies that participated in this study include the WES and the U. S. Army Cold Regions Research and Engineering Laboratory (CRREL). The fieldwork for this study was conducted in Thailand during the period 1 July 1964-7 May 1965. Personnel from the above agencies who participated in fieldwork are as follows:

U. S. Army Engineer Waterways Experiment Station

Geology Branch (GB), Soils Division

Mr. W. K. Dornbusch, Jr.*	Geologist
Mr. J. D. Broughton*	Geologist
Mr. D. E. Andrews	Geologist

Area Evaluation Branch (AEB), Mobility and Environmental (M&E) Division

Mr. H. West	Engineer
Mr. A. P. Desmarais	Engineer
Mr. V. J. Piazza	Engineering Technician
Mr. W. W. Allred	Engineering Technician
Mr. B. T. Helmuth	Engineering Technician
Mr. C. Lebron-Rodriquez	Engineering Technician
Mr. A. Vazquez	Engineering Aide

MERS Field Detachment, Bangkok, Thailand

Mr. E. E. Garrett	Supervisory Geologist
Mr. B. O. Benn	Engineer
Mr. C. A. Blackmon	Engineering Technician
Mr. Ruangvitya Chotivittayathanin*	Engineer
Mr. Chalaj Choeyapunt	Engineer
Mr. Phayond Trunshigone	Engineer
Mr. Sarid Sriphirom	Engineer
Mr. Shriwiroj Chantawong	Engineer
Mr. Anuvat Laophanich	Engineer
Mr. Thamnoon Mongkol	Engineer
Mr. Chamnan Vichitlaksana	Engineer
Mr. Boonkiat Sirimontaporn	Engineer
Mr. Kasem Imkasorn	Engineer
Mr. Manit Churanakoses	Engineer
Mr. Suchart Supaphol	Engineer
Mr. Sanchai Vongthavarravat	Engineer

* Served as Data Collection Leader for periods of three to four months.

MERS Field Detachment,
Bangkok, Thailand (continued)

Mr. Chamras Singhuwongse	Engineer
Mr. Taweesak Suwanpitak	Engineer
Mr. Kamol Sookphaithya	Engineer
Mr. Vichai Krisnawan	Engineering Technician
Mr. Kamol Vitayaudom	Engineering Technician
Mr. Sermsak Sangpo	Engineering Technician
Mr. Panom Chuersuwan	Engineering Technician
Mr. Tawee Klinproung	Engineering Technician
Mr. Boontham Penchan	Engineering Technician
Mr. Boonlip Sirimontarorn	Engineering Technician
Mr. Sugrirat Parnsrikas	Engineering Technician

U. S. Army Cold Regions Research and Engineering Laboratory
Photographic Interpretation Research Division

Mr. R. E. Frost*	Engineer
Dr. P. L. Johnson	Ecologist
Mr. R. D. Leighty	Engineer
Mr. V. H. Anderson	Geologist
Mr. A. O. Poulin	Engineer
PVT L. A. Colyer	Physicist
PVT G. Cunningham	Geologist

The data analysis and map preparation reported in Volumes II-V, and the compilation of the maps included in Volume VIII were performed at WES by four teams with Mr. J. H. Shamburger, Geology Branch (GB), in charge of this phase of the study. The teams and members of each are shown below:

Surface Composition

Mr. J. R. Burns**	AEB Geologist
Mr. G. E. Schabilion	AEB Soil Scientist
CPT R. C. Wright	AEB Geologist

Surface Geometry

Mr. W. K. Dornbusch, Jr.+	GB Geologist
Mr. D. E. Andrews	GB Geologist
Mr. H. K. Woods	GB Geologist
Mr. V. J. Piazza	AEB Engineering Technician

* CRREL Project Leader.
** Team Captain, on detail from Military Geology Branch, U. S. Geological Survey.
\+ Team Captain.

Vegetation

Mr. J. D. Broughton*	GB Geologist
Mr. E. E. Addor	AEB Botanist

Hydrologic Geometry

Mr. E. E. Garrett*	AEB Supervisory Geologist
Mr. H. W. West	AEB Engineer
Mr. M. A. Zappi	AEB Geologist
Mr. W. W. Allred	AEB Engineering Technician

The scientists or engineers who prepared each of the volumes are: Messrs. Shamburger and Grabau, Volume I; Mr. Burns and CPT Wright, Volume II; Mr. Dornbusch, Volume III; Messrs. Broughton and Addor, Volume IV; Messrs. Garrett and Shamburger, Volume V; Messrs. Frost, Leighty, Anderson, and Poulin and Drs. Johnson and J. N. Rinker, CRREL, Volume VI; and Mr. Dornbusch, Volume VII. Volume VIII was prepared by the factor-family teams.

Acknowledgment for support and cooperation during the field sampling is made to MAJ GEN Singchai Menasuta, Royal Thai Army, former Commanding General of the Military Research and Development Center, Thailand; Mr. T. W. Brundage, former Director of ARPA Research and Development Field Unit in Thailand, and LTC A. R. Simpson, U. S. Army, Director of the MERS Field Detachment. Technical assistance in various phases of the work was provided by Mr. A. A. Rula, Chief, Mobility Environmental Research Studies Branch, WES. All phases of this study were conducted under the direct supervision of Mr. W. E. Grabau and Dr. C. R. Kolb, Chiefs of Area Evaluation and Geology Branches, respectively, and Mr. W. B. Steinriede, Jr., former Chief, Geology Branch, and under the general supervision of Messrs. W. G. Shockley and S. J. Knight, Chief and Assistant Chief, respectively, of the M&E Division, and Messrs. W. J. Turnbull and A. A. Maxwell, Chief and Assistant Chief, respectively, of the Soils Division.

Directors of the WES during the conduct of this study and preparation of this report were COL Alex G. Sutton, Jr., CE, and COL John R. Oswalt, Jr., CE. Technical Director was Mr. J. B. Tiffany.

---

* Team Captain.

CONTENTS

BLANK PAGE

GLOSSARY

The following terms have been used in highly restricted senses throughout this report. The form in parentheses is commonly used in the text as an effective abbreviation.

Terrain factor (factor). An attribute of the terrain that can be adequately described at any point (or instant of time) by a single measurable value. For example, slope and plant stem diameter are both factors.

Terrain factor value (factor value). A specific occurrence of a terrain factor. For example, 17 deg is a factor value of the terrain factor slope.

Terrain factor family (factor family). A combination of factors that in concert tend to exert a characteristic kind of effect on a military vehicle or activity. Four factor families have been identified by cross-country locomotion analysis: surface composition, surface geometry, vegetation, and hydrologic geometry.

Terrain factor value set (factor value set). The array of all factor values required to define the conditions at a given place and/or time.

Terrain factor value class (factor value class). A specific range of factor values established for a specific purpose. For example, 1.5-4.5 deg is a factor value class of the factor slope.

Terrain factor value class set (factor value class set). A combination of factor value classes relating to two or more factors and chosen for a particular purpose, as required to define conditions over an area and/or over a period of time.

Terrain factor complex (factor complex). Any combination of two or more factors chosen for a specific purpose. They may or may not all be drawn from the same factor family. For example, the 19 factors identified

in table 1 of this report comprise the factor complex required for vehicle locomotion analysis.

Terrain factor map (factor map). A map delineating areas, throughout each of which the terrain is characterized by a unique factor value class.

Terrain factor-complex map (factor-complex map). A map in which each delineated area exhibits, throughout its extent, a specific combination of factor classes, the factors having been chosen for a specific purpose. The factors may be drawn from one or more factor families. A map where the combinations of factor classes are restricted to a specific family is a terrain factor-family map (factor-family map).

The terminological scheme can be illustrated graphically:

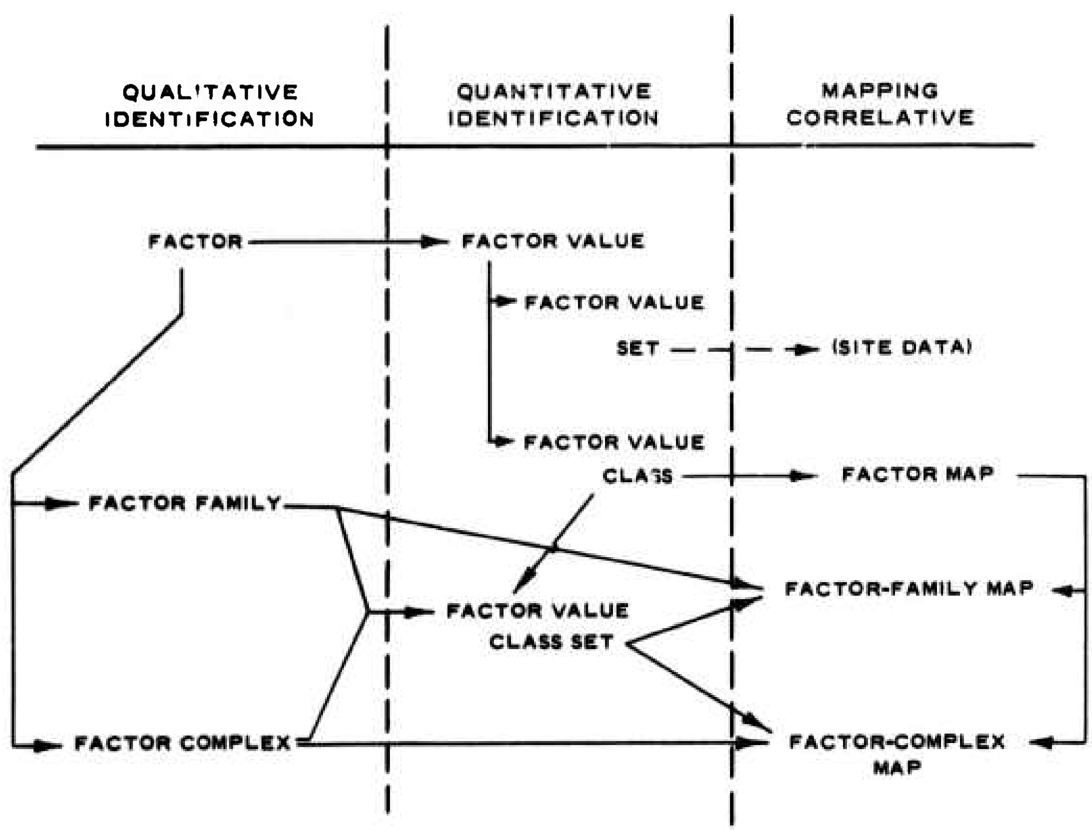


Diagram of relations among terms used in factor mapping

SUMMARY

Knowledge of exact terrain conditions and vehicle characteristics is a prerequisite for predicting vehicle performance across terrain. This volume discusses in general terms the procedures that were used to acquire the necessary quantitative terrain information and the techniques that were employed to adapt these data to displays that meet the specific requirements of cross-country locomotion analysis.

The development of an analytical model for predicting the cross-country speed of ground-contact military vehicles (see: An Analytical Model for Predicting Cross-Country Vehicle Performance, Technical Report No. 3-783, U. S. Army Engineer Waterways Experiment Station, in preparation) resulted in the isolation of those terrain factors that significantly affect the locomotion of ground-contact vehicles. Since atmospheric conditions were specifically eliminated from considerations by the study specifications, the factors discussed in this report are encompassed in four factor families: surface composition, surface geometry, vegetation, and hydrologic geometry.

Since a condition of the study was to establish the effects of terrain on vehicle locomotion in Southeast Asia, seven primary study areas were selected in Thailand. These areas were selected not because each was presumed to characterize or typify geographical regions, but because they contain in sum all of the terrain types or conditions that have been recognized as being significant to cross-country mobility in Thailand. These areas are in the vicinities of Nakhon Sawan, Lop Buri, Chiang Mai, Pran Buri, Khon Kaen, Chanthaburi, and Hat Yai.

It was recognized from the beginning that the mapping of terrain factors over significantly large areas could be accomplished only by interpretation of aerial photographs (air photos). Teams were assigned responsibility for acquiring data in the field in the primary study areas to provide the necessary ground control, and to define in quantitative terms the conditions affecting ground-contact locomotion. Approximately 2400 sites were sampled within six of the study areas (Hat Yai was eliminated as a study area during a reprogramming of Project MERS in 1964) during the period 1 July 1964-7 May 1965. The measurements were made according to established procedures. The raw field data were reduced by other teams, and specific factor values were presented in tabular form. Significant class ranges for each factor were established after thorough analysis of the reduced data. Utilizing the field data, a method was developed for estimating the established terrain factor value classes from

the geometric, tonal, and textural characteristics of the photographic patterns. Terrain characteristics were extrapolated from the sampled to the unsampled areas, and factor-family maps at a scale of 1:50,000 were prepared of the six study areas for which ground data were available. These maps were then compiled into factor-complex maps for ground mobility purposes.

A catalog of selected Thailand terrain features was compiled. This catalog presents the characteristics of these features in terms of recognition on air photos, appearance on the ground, dimensions, relations to other features, and regional distribution. This effort was restricted primarily to the Lop Buri and Chanthaburi study areas.

This report is presented in eight volumes. Volume I is a summary. Data collection, reduction and analysis procedures, and techniques for mapping the specific factors of each factor family are presented in Volume II (Surface Composition), Volume III (Surface Geometry), Volume IV (Vegetation), and Volume V (Hydrologic Geometry). Data summaries are included as appendixes to the appropriate volumes. Air-photo interpretation techniques used to identify air-photo patterns of terrain features are presented in Volume VI. The method used to synthesize the factor-family maps into factor-complex maps for mobility purposes is presented in Volume VII. Map sets for each of the four factor families for the six study areas are presented in Volume VIII.

MOBILITY ENVIRONMENTAL RESEARCH STUDY

A QUANTITATIVE METHOD FOR DESCRIBING TERRAIN FOR GROUND MOBILITY

VOLUME I: SUMMARY

PART I: INTRODUCTION

Background

1. The major objective of the Mobility Environmental Research Study (MERS), as originally stated, is to establish the relation among the various features of the physical environment as they affect surface vehicle mobility and to derive therefrom data and vehicle design parameters that can be used by designers in computing vehicle design and predicting design results. In order to predict the performance of a vehicle across specific terrain, it is necessary to know the mechanical and geometric characteristics of the vehicle, the characteristics of the terrain, and the type and magnitude of effects that the terrain characteristics will produce on the performance of the vehicle. Similarly, if a vehicle with improved performance is to be designed, the exact nature of the terrain characteristics that it will be expected to encounter must be known. Therefore, knowledge of exact terrain characteristics is a prerequisite for both mobility analysis and vehicle design.

2. It was apparent from the inception of the MERS Project that a single system for describing those terrain factors that inhibit or otherwise affect the cross-country performance of vehicles would be required. Examination and evaluation of the various systems for describing terrain were begun immediately to determine whether any existing systems, either whole or in part, contained descriptive procedures that would provide data suitable for vehicle mobility purposes. The general intent was to modify the existing systems on the basis of discovered techniques, if practicable, or to replace existing procedures if fundamentally different but demonstrably better procedures were found.

Purpose

3. The purpose of this study was to develop a quantitative method for describing terrain for ground mobility. In so doing, it was necessary to (a) collect, tabulate, and analyze data on surface composition, surface geometry, vegetation, and hydrologic geometry that would adequately describe the significant terrain variations occurring in seven selected areas of Thailand in terms that will make determination of terrain-vehicle relations possible; (b) develop a method for interpreting, classifying, and mapping terrain factors of Thailand from aerial photographs (air photos); and (c) utilize the field data and the air-photo interpretation method in preparing factor-family and factor-complex maps.

4. The specific purposes of this volume of the report are to: (a) present in summary form the general approach to the problem, and (b) present rationale and procedures used in the development of factor-family and factor-complex maps. This volume also presents important conclusions and recommendations established during the course of this study.

Scope

5. The field data collection was intended to provide only enough data to determine the probable range in variation of significant terrain factors and to permit the mapping of the areal distributions of these factors within seven primary study areas in Thailand. It was assumed that most of the significant terrain variations occurring in Thailand could be included in seven primary study areas (fig. 1). However, there was some uncertainty as to whether these areas were completely adequate to represent all of the significant variations occurring in Thailand, and eight secondary study areas (fig. 1) were also selected where geographic theory suggested that important terrain variations might be expected to occur. The reprogramming of Project MERS during the latter part of 1964 resulted in the elimination of the secondary study areas and the Hat Yai primary study area from the project.

6. This report consists of eight volumes that are concerned with the MERS tasks entitled "Vegetation, Surface Geometry, and Hydrologic

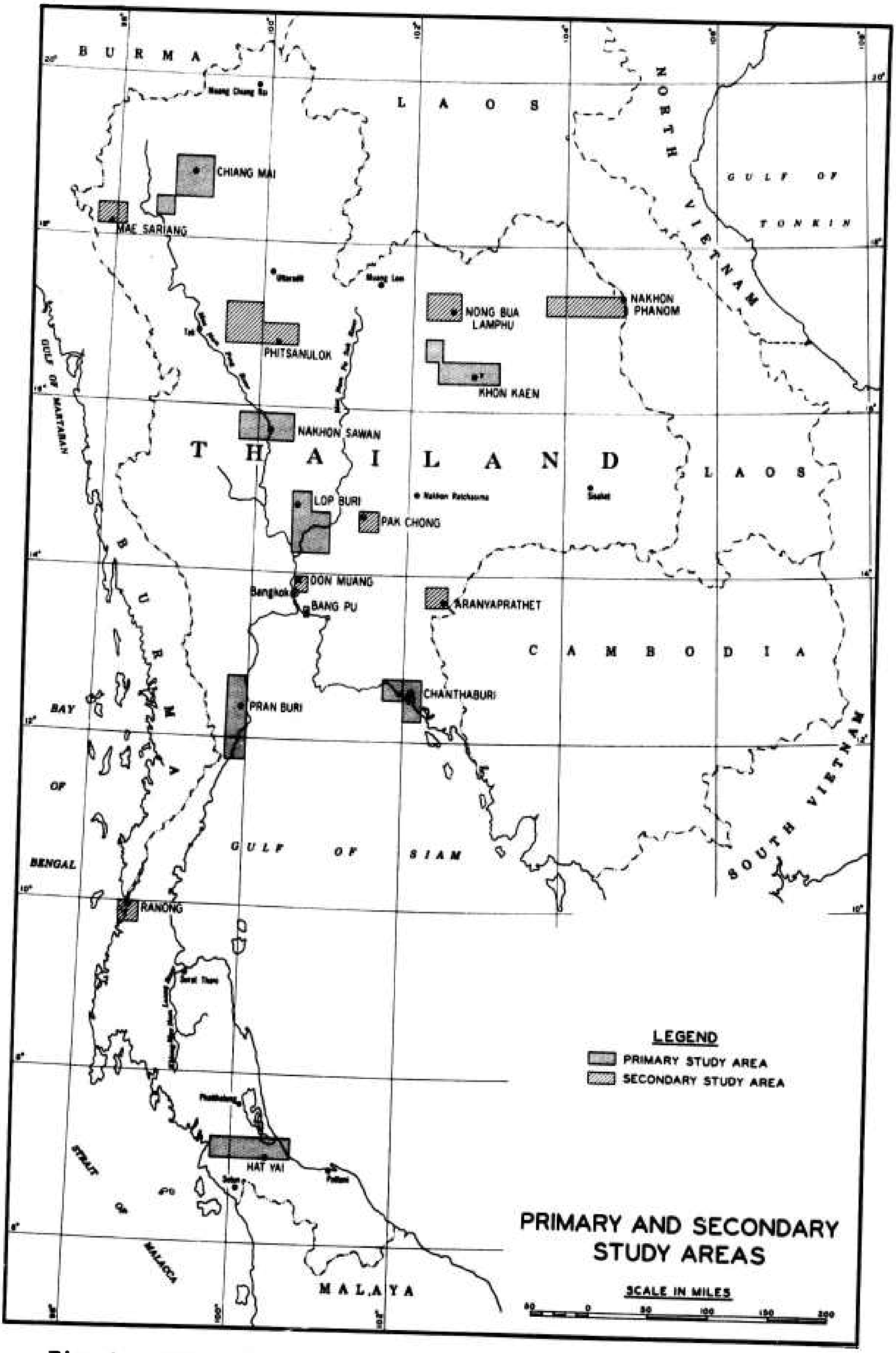


Fig. 1. Original primary and secondary study areas in Thailand

Geometry of Selected Areas in Thailand," "Interpretation of Terrain Factors of Selected Areas in Thailand from Aerial Photographs," and "Trafficability Characteristics of Soils of Selected Areas in Thailand." This, the first volume, presents the factor-family concept, the reasons for selecting the study areas, the procedures used in selecting sites for detailed measurements of the terrain factors, the approach used in data reduction, classification, photo interpretation, and mapping, and a summary of procedures for compiling the factor-complex maps. The procedures for collecting, reducing, and analyzing data and the techniques used for analyzing the study areas in terms of each of the factor families are presented in Volumes II through V, with each factor family comprising a separate volume. Volume II concerns surface composition, Volume III pertains to surface geometry, Volume IV presents vegetation, and Volume V contains hydrologic geometry. Air-photo interpretation techniques used to identify air-photo patterns of terrain features are presented in Volume VI, and the method used to construct factor-complex maps for mobility purposes is covered in Volume VII. A folio of factor-family maps is presented as Volume VIII. Data summaries are included as appendixes to Volumes II through V.

PART II: GENERAL APPROACH TO THE PROBLEM

Fundamental Problem

7. The function of military terrain analysis is to supply an interpretation of terrain in terms of performance values (or classes) of a military machine or activity. Thus, a capability for military terrain analysis presupposes a capability for describing the terrain in the terms required as input to a performance prediction analysis. Assuming that the performance prediction employs a mathematical model, it is apparent that the terrain must be described in quantitative terms, and that those terms are dictated by the input requirements of the model.

8. The analytical model for predicting the cross-country speed of military vehicles developed for Project MERS* required quantitative statements of the pertinent terrain factors. These are identified in table 1. The requirements were threefold:

- a. Development of a procedure for measuring the required terrain factors in the field, both to identify the total range of variation that needs be considered, and to provide ground truth data for interpretation of air photography;
- b. Development of techniques for estimating the factor values (or at least useful classes of values) by interpretation of air photos, because it is apparent that any evaluation of significantly large areas will have to be accomplished through photo interpretation; and
- c. Development of a scheme for mapping those factor value classes that are acceptable as model input, because only through the use of such maps can the vehicle performances be predicted for every point in the area of investigation.

9. An evaluation of the state-of-the-art of terrain description and terrain analysis for ground mobility purposes revealed that there was no existing scheme for describing and evaluating terrain that satisfied all the necessary requirements. However, an examination of the descriptive systems being developed at WES unde the Army Materiel Command (AMC)

---

* U. S. Army Engineer Waterways Experiment Station, CE, "An Analytical Model for Predicting Cross-Country Vehicle Performance," Technical Report No. 3-783, Vicksburg, Miss. (In preparation.)

sponsored Military Evaluation of Geographic Areas (MEGA) project revealed that the MEGA systems could be made suitable with a few modifications. The MEGA systems for measuring and recording terrain factors contained a substantial number of factors that were not needed for purposes of mobility analysis. Since each factor was considered as independent of all others, those not needed for mobility analysis could be readily dropped, and only those factors that were known or hypothesized to produce an effect on mobility retained. The result of this process was the establishment of a useful and at least temporarily adequate description of terrain for mobility purposes.

The MEGA Terrain Description System

10. The MEGA system for describing terrain is based on the principle that all attributes of the terrain that are significant for any specified purpose (i.e., that can be demonstrated or hypothesized to affect a military machine or activity) can be isolated and measured. A sufficient description of a specified terrain consists of the array of values obtained by measuring the significant attributes (or factors) in that terrain. It is commonly convenient to stratify these factor arrays in terms of the characteristic kind of effect that they impose on a specified military activity. In the present case, this is cross-country locomotion. For example, the effects produced on vehicle locomotion by the shape of the topographic surface are generally different in kind from those produced by bodies of water. Although there are many exceptions to this general rule, the suggestion remains that a division of the environment into families of related attributes is both reasonable and convenient in the terrain description process. This grouping of terrain factors into factor families is referred to as the factor-family concept, and convenient (although not necessarily entirely accurate) names are assigned them. Thus, in table 1, the first four factors belong to the surface geometry factor family, the next three are members of the surface composition factor family, the next eight are included in the vegetation factor family, and the last four are components of the hydrologic geometry factor family. Although the individual factor

families conceptually incorporate all factors relevant for all possible purposes (paragraphs 12-21), only those listed in table 1 were actually mapped for the MERS Project.

11. In the process of developing the MEGA terrain description system, a number of procedures for measuring factor values in the field had been developed. Further, the field routines included the concept that the acquired data should if possible be recorded in a format that would be readily transcribable into input formats for automatic data processing (ADP) machines. While the concept existed, the level of development was very low; as a result, both data acquisition procedures and data recording procedures were developed to a much greater level of sophistication during the MERS Project. These developments are discussed in detail in Volumes II through V.

12. The apparent complexity of the descriptive system appears to be unavoidable, chiefly because all natural environments are composed of many factors, and any activity conducted therein will be simultaneously affected by many of those factors acting either individually or in concert. For example, a vehicle traversing a hill is affected by a combination of the soil consistency, the slope angle, the degree of surface roughness, and the vegetation. On the other hand, different and varying combinations of terrain characteristics may produce the same total effect on a vehicle's progress. Thus, a combination of vegetation and soft soil may produce the same impedance to vehicle movement as does slope alone. When it is considered that terrain occurs in an almost infinite combination of conditions, it is clear that any system which attempts to describe all conditions simultaneously becomes complex. The only reasonable solution appears to be to divide the total array of terrain characteristics into groups of factors that tend to act in a common manner on any specific activity. It is primarily for this reason that the MEGA system incorporates the factor-family stratification of factors, as discussed in paragraph 10 above. It is a convenient simplification, and not a necessary part of the terrain description process. Nevertheless, it does make it easier to define and describe the more or less naturalistic factor groups, as follows.

Surface geometry

13. This factor family is concerned with the configuration of the surface of the earth without regard to origin or composition. Such things as slopes, ravines, embankments, ditches, plowed fields, boulder fields, and ricefield dikes are typical surface configurations that produce profound effects on various military activities including the mobility of vehicles. It must be emphasized that consideration of this factor family is governed only by actual physical shape, size, and arrangement; it is not concerned with what caused the feature or whether it is man-made or of natural origin. In short, this factor family is simply the geometrical configuration of a three-dimensional surface.

Surface composition

14. This factor family is concerned with the composition and physical properties of the materials of the surface of the earth without regard to their origin. The study reported herein is concerned chiefly with soils as an engineering material, to the exclusion of such materials as consolidated rocks, snow, and ice, even though in a general sense such materials are included in the surface composition factor family. For the purposes of analysis of terrain for various military activities, such as construction of roads and airfields, mobility of ground-contact vehicles, and construction of field fortifications, the consideration of soils is divided into three data-collection categories: soil classification, soil moisture, and engineering characteristics.

15. Soil classification encompasses the identification of basic physical characteristics, such as texture, mineralogy, and structure. In general, the soil classification used in this study was the Unified Soil Classification System (USCS).

16. Soil moisture is a basic constituent of the surface materials, but it is not encompassed in most classification processes primarily because it nearly everywhere varies with time. All other things being equal, it is the most important factor controlling soil strength. Thus, detailed information on the relation between soils and moisture content is necessary before engineering properties of the material can be predicted.

17. Engineering characteristics of soils comprise a group of related factors describing specific physical properties of the soil-water system as a whole. The factor values are stated as numerical indicators derived from standard laboratory or field tests, and include Atterberg limits and measures of soil strength. Soil strengths are measured in terms of mass strength and surface strength.

Vegetation

18. This factor family includes two related assemblages of properties: vegetation structure, and screening characteristic. Each of these deals with particular characteristics of vegetation as a whole. In this context, vegetation includes all plants growing on the surface of the earth, on other plants, or in or on water; that is, it incorporates both terrestrial and aquatic vegetation structures.

19. Vegetation structure comprises the relatively gross physical attributes of plant growth. It is the geometry of the vegetation as a whole and incorporates those physical properties known or assumed to produce direct effects on military activities; the factors include stem size and spacing, height, branching characteristics, etc.

20. Screening characteristic of vegetation is an "artificial" property of vegetation in the sense that it is an arbitrary measure of an effect of the vegetation structure on a specific activity rather than a measure of a direct physical attribute of plants themselves. The property measured is the effect of plant growth of varying density on visibility along selected lines of sight.

Hydrologic geometry

21. This factor family is concerned with the shape, size, and distribution of water bodies of all kinds. Here, temporal variance is a matter of very great concern, since these shapes, sizes, and distributions vary with time. There are also dynamic considerations, such as current velocity. For example, water splash created by high current velocities can drown out an engine and immobilize a vehicle just as effectively as can excessive water depth.

PART III: PROCEDURES FOR DESCRIBING TERRAIN

22. The description of terrain for mobility analysis, as applied in Project MERS, consists of three fundamental steps, as described in paragraph 8: obtaining field data, estimating factor values over large areas by air-photo interpretation, and mapping significant and useful factor value classes over those areas. A number of subsidiary steps and considerations are involved in each of these three general classes of activity.

Acquisition of Field Data

Selection of study areas

23. Because a condition of the MERS Project is that the characteristics of terrain in Southeast Asia that significantly affect cross-country mobility be established, and because the terrain of that region is extremely complex and variable, it was apparent that a number of study areas would have to be selected. It was obviously impractical to attempt to map all of Thailand (approximate area 518,000 sq km) in the detail required by the analytical model. Four other general considerations were deemed to be important:

- a. It was contemplated that cross-country mobility tests would be conducted in at least some of the study areas. These tests required very close experimental control, and relatively complex instrumentation. These considerations implied the necessity to work out of fairly well established bases, which in turn implied that the test areas should be reasonably compact in order to keep travel time to a tolerable level.
- b. The U. S. Military Research and Development Center (MRDC) Bangkok, Thailand, indicated they would use these areas for purposes other than vehicle mobility tests. This suggested an even more refined and detailed study than was originally contemplated.
- c. Nearly all land in Thailand is in small private holdings. Thus, acquisition of suitable areas for test purposes would involve dealing with innumerable individuals. Obviously, the more compact the areas, the easier it would be to obtain easement rights.
- d. The study area should be as representative of all of Southeast Asia as possible.

24. Item d was an especially difficult problem. A survey of technical literature on Southeast Asia conducted as part of the MERS Project* indicated that the available data for the other Southeast Asian countries were not so detailed as the Thailand data. Moreover, much of the published data could not be interpreted for mobility purposes. The description and classification systems employed by the various authors were intended to satisfy purposes not related to military affairs, vehicle mobility, or engineering activities, and as a result the terms could not be correlated with the specific quantitative factor values required for predicting vehicle performance. For example, a typical forestry map would identify yang forests and teak forests, because this distinction is economically important; however, examination of both revealed that stem spacing (one of the most critical values for mobility evaluation) ranged from 10 to 200 ft (3 to 61 m) in both forest types. This spacing encompasses the whole range of values significant from a mobility standpoint, and a distinction between yang and teak forests appears to be inconsequential.

25. Because of the lack of pertinent quantitative data, the task of objectively selecting areas that would be representative of all of Southeast Asia was practically impossible. In this context, the problem being faced was that of selecting areas representative with respect to mobility characteristics, but regions delineated on the basis of traditional criteria (i.e., geological, physiographic, climatic, etc.) did not exhibit internally consistent combinations of significant terrain factor values. For example, a random sample of the Korat Plateau, a unit on a geographic and/or physiographic region map, would not necessarily be representative of the entire plateau. As a matter of fact, it usually develops that not even one compact area can be found that will represent an entire region if the criteria for selection and representation are restricted to mobility parameters. For example, the Khon Kaen study area is not intended to represent the mobility characteristics of the Korat Plateau but to represent a set of terrain types characterized by specific ranges of factor values.

* J. D. Broughton, J. H. Shamburger, and D. B. Del Mar, "Mobility Environmental Research Study; A Literature Survey of Environmental Factors in Thailand," Technical Report No. 3-681, Report 1, June 1965, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Such terrain types occur in various places throughout Southeast Asia, on the Korat Plateau, and elsewhere.

26. Because quantitative and mobility-oriented data were lacking for regions other than Thailand, great dependence was placed on subjective decisions in the choice of primary study areas. The following criteria were established based on a study of all available data, personal observations of the selectors, and the selectors' understanding of terrain-vehicle relations.

a. Surface geometry is an important factor inhibiting vehicle speed; therefore, the areas selected should contain examples of all known kinds and sizes of small-scale surface irregularities.

b. Soil characteristics, especially in relatively nonvegetated areas, exert a major control on vehicle speed. Therefore, the areas selected should contain extensive regions of soils exhibiting all ranges of both soil mass strength and soil surface strength found in either areally or positionally significant locations in Southeast Asia.

c. Under certain circumstances, vegetative obstacles are the major inhibiting properties of terrain. Therefore, the areas selected should contain reasonably large areas exhibiting the spacing of large trees most characteristic of Southeast Asia, and the spacings and stem size combinations of relatively small plants that are either areally or positionally significant.

d. Water bodies have traditionally been a source of difficulty for cross-country vehicles. However, they become serious problems for nonfloating vehicles only when the water depth exceeds the fording depth, and for floating vehicles when the water depth is such that the vehicle almost or completely floats. It is at the transition from water to land that immobilizations frequently occur. Accordingly, the study area should contain examples of as many bank configurations as possible, but those configurations must be associated with water in excess of about 1.3 ft (0.4 m) in depth.

e. A factor value set drawn from a single factor family rarely exists in isolation; effects on vehicles are normally the result of two or more factor-family sets acting in concert. Therefore, the selected test areas should contain examples of at least a substantial number of the combinations that commonly occur in Southeast Asia.

f. The areas should be accessible, which in this study means on an all-weather road or railroad and near a major town.

27. All WES personnel who had traveled in Southeast Asia were polled, and the seven primary study areas identified in fig. 1 were selected. Because a measure of uncertainty remained as to whether these seven areas contained all significant terrain types characteristic of Southeast Asia, eight secondary study areas (fig. 1) were also chosen. The plan called for the secondary areas to be examined in enough detail to permit a determination as to whether or not they contained important environmental situations not encompassed by the seven primary areas. However, the reduction in scope of Project MERS necessitated eliminating the primary study area at Hat Yai and dropping the secondary study areas after only a cursory examination had been made.

Data collection program

28. Prior to the actual beginning of the field data collection program in the six primary study areas in Thailand, the MEGA factor measurement and data recording procedures were reviewed and modified to meet the specific requirements of mobility analysis. The field procedures and data recording forms and instructions are presented in detail for each factor family in Volumes II through V, inclusive.

29. Selection of appropriate sample sites was a continuing problem. The available background consisted of the experience of a few engineers and scientists who had traveled widely in Thailand,* and of air-photo coverage. Unfortunately, the air photos were all 10 to 12 years old, and in many cases, the present conditions differed substantially from those recorded on the photos. The general procedure involved first a brief study of the air photos by the experienced personnel. Sites for each factor family were then selected on the basis of assumed interpretation. Where interpretations were uncertain (as was frequently the case), sites were located on the basis of obvious differences in tone, texture, and pattern. A continuing constraint was the recognition that the motorable road network is very sparse, and that a site more than a few hundred meters from a road was likely to be completely inaccessible. Thus,

---

* U. S. Army Engineer Waterways Experiment Station, CE, "Environmental Factors Affecting Ground Mobility in Thailand; Preliminary Survey," Technical Report No. 5-625 (with Appendixes A-H), May 1963, Vicksburg, Miss.

every effort was made to locate sites near a road or motorable trail, or a navigable stream. After selection, the sites were examined by low-altitude air reconnaissance, wherever possible, and appropriate adjustments were made. Finally, a ground reconnaissance was made by the field party chief to check out the sites selected by photo interpretation and air survey. This ground check also frequently revealed environmental variations that had previously been overlooked. The ground reconnaissance proved to be essential; some of the trails were found to be impassable even for four-wheel-drive vehicles. When sites could not be reached, alternate sites were selected whenever possible.

30. The data collection program was initiated on 15 July 1964, and the first phase was completed on 6 January 1965. During this time, five study areas (Nakhon Sawan, Lop Buri, Chiang Mai, Khon Kaen, and Chanthaburi) were sampled. The second phase of the data collection program was begun on 15 February and was continued until 7 May 1965. During this time, the Pran Buri study area was sampled, and additional data were gathered in the Lop Buri and Chanthaburi areas. A total of 2387 sites were sampled. A site is an area within which detailed field measurements were made. Table 2 lists the number of sites by study area and factor family.

31. During the data collection, the field parties were divided into four factor-family teams. Each team was responsible for obtaining field measurements for the factor family assigned it. A data collection leader was placed in charge of all the field sampling teams and was responsible for selecting sampling sites. The sites were then assigned to the teams; the surface geometry sampling team was given those sites for which the principal reason for selection was surface configuration; the vegetation team was given those sites selected as illustrative of distinctive vegetation patterns, etc. Sites containing a mixture of pertinent factor families were visited by whatever teams were necessary to make an appropriate evaluation.

32. The sampling teams were also empowered to select additional sites if they believed it to be necessary or useful to do so. Theoretically then, site selection was to have continued until the particular factor family for which each team was responsible was adequately sampled. However,

the urgencies of the project schedule usually demanded that the teams move to the next study area before a thorough sampling program could be completed. Nevertheless, it is believed that the gaps in the sampling program represent only a minor part of the terrain conditions occurring in the study areas.

Estimation of Factor Values by Air-Photo Interpretation

33. The process of extrapolating the highly detailed site descriptions to techniques for interpreting air photos of large areas in terms of factor values involved four major steps, as discussed below. Four terrain evaluation teams were organized, one for each factor family. They worked largely independently. However, the basic problems that were encountered were common to all, and are discussed herein in general terms. Detailed discussions are given in Volumes II through V.

Data reduction

34. The first step in handling the incoming field data was to reduce them to a form whereby appropriate parameters could be easily studied. It was assumed that the data for each factor family would probably be arranged in a number of different ways before satisfactory relations could be found. This led to the design of key-sort cards for data storage. An example of a card holding all of the data on the significant surface geometry factors (see table 1) at one sample site is given in fig. 2. Similar arrangements were used for the other factor families.

Factor classification

35. It will be recalled that the terrain factors (table 1) that were measured in the data collection program had been isolated because they were essential to the vehicle performance prediction model. Further, the factor-family maps, which were envisioned as the end product of the terrain description process, would constitute the data store from which the terrain factor input to the performance prediction model would be obtained. However, in order to show factor values as areal phenomena rather than as a number of isolated points, it is necessary to erect classes of factor

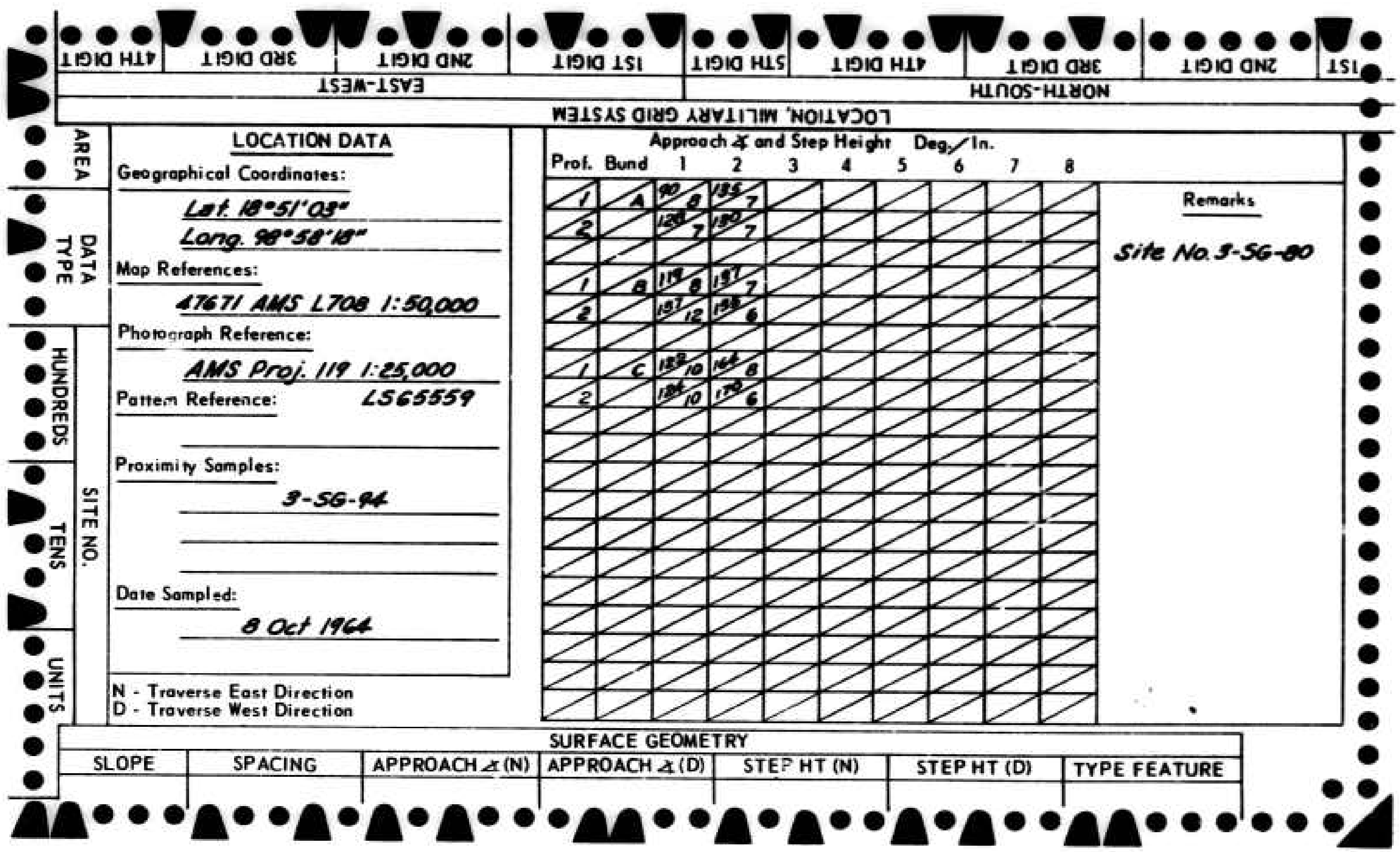


Fig. 2. Arrangement of surface geometry site data on key-sort punch card

values. Each such factor value class will then be a map unit (see diagram in Glossary).

36. This relatively simple process of fitting classes to vehicle characteristics was complicated by the fact that the classes also had to be recognizable, or at least interpretable, from air photos because the only practical method of extrapolating data to large unsampled areas was by means of photo interpretation. Little could be accomplished by insisting on a class interval if that class could not be mapped. As a result, the class units eventually chosen are in every case compromises between the desires of mobility predictors and the realities of meeting practical mapping criteria. For example, soil mass strength was arbitrarily subdivided into three ranges rather than five ranges between 10 and 100 RCI (rating cone index). In nature, soils rarely occur below 10 RCI; above 100 RCI the soil strength is more than adequate to permit 1 or 50 passes of most military vehicles. The factor value classes that were eventually chosen for all factor families are given in table 3.

Photo-interpretation techniques

37. Although a large amount of data was collected by the field teams within the six primary study areas, a map with the sample points located thereon reveals that vast areas remained unsampled. The only practical method of actually mapping the study areas was by photo interpretation. However, there were difficulties.

38. Since it was known that many of the pertinent factor values could not be measured at any practicable scale and that their values would have to be interpreted from air photos, it was evident that new photo-interpretation procedures for objectively defining terrain conditions as characterized by photo patterns needed to be developed. Photographic coverage of all the study areas was available at scales ranging from 1:20,000 to 1:50,000 (fig. 3); however, the photographs were from 10 to 12 years old, and the quality varied from good to poor. Since it was well known that the degree of reliability of interpretation from air photos varies with the scale and quality of the photographs, it seemed likely that the photography available at the inception of the project would be

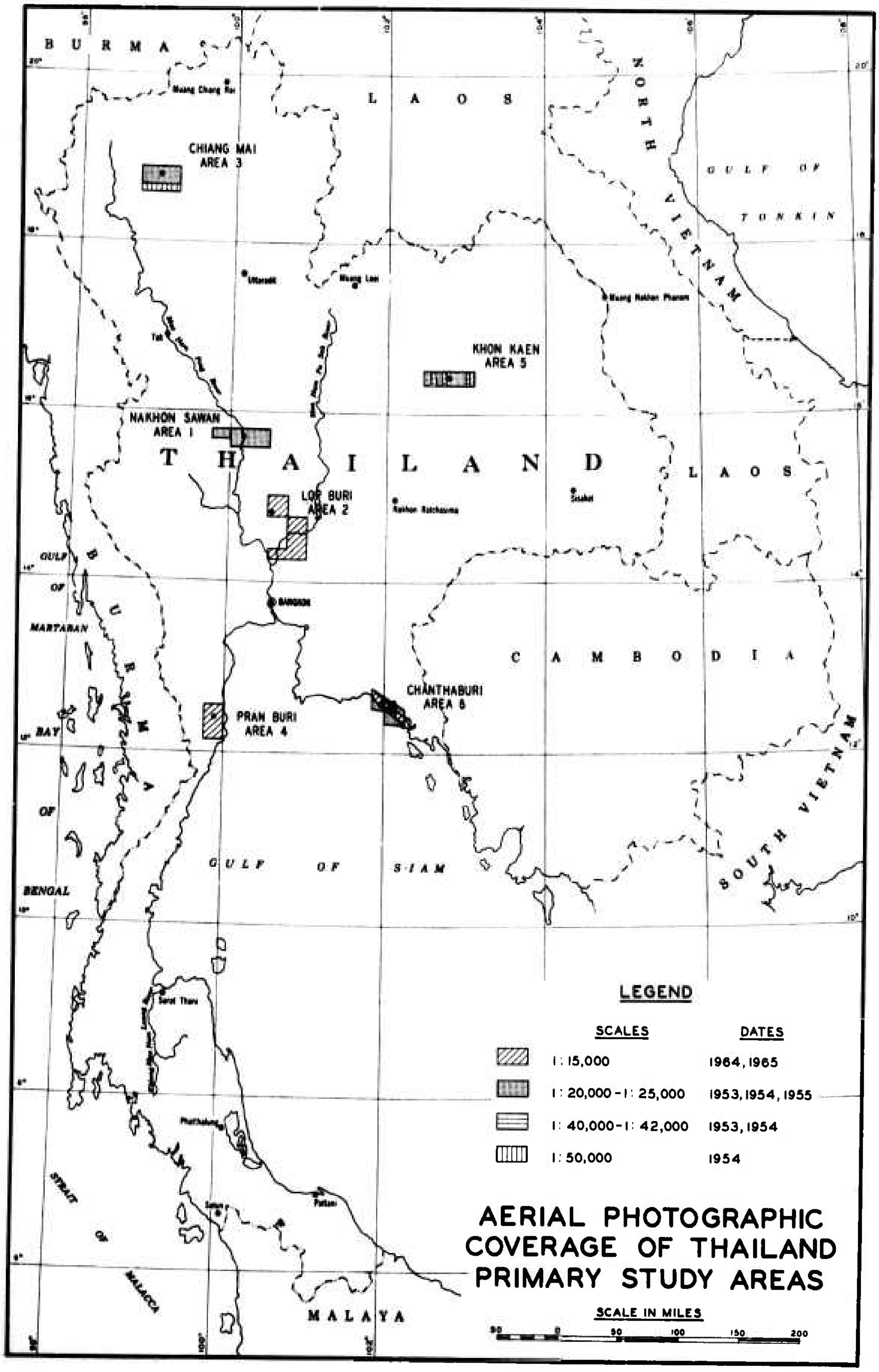


Fig. 3. Final primary study areas, indicating scale of air-photo coverage available

inadequate for interpretation of the degree of detail required by the analytical vehicle performance model.

39. The U. S. Army Cold Regions Research and Engineering Laboratory (CRREL) was solicited for assistance in overcoming the related problems of inadequate photography and inadequate interpretation techniques. A contract was let to obtain 1:15,000 panchromatic photography of the primary study areas. Also included in this contract were selected strips at a scale of 1:5,000 using panchromatic, passive-infrared, and camouflage-detection film. Unfortunately, the weather permitted the contractors to fly new coverages in only two areas (Lop Buri and Pran Buri) in time to be utilized in the mapping program. These air photos were of excellent quality and significantly increased the reliability of the factor value interpretations. The factors in the remaining four areas (Nakhon Sawan, Chiang Mai, Khon Kaen, and Chanthaburi) were mapped utilizing the existing air photos (scales ranging from 1:20,000 to 1:50,000, flown 1953 through 1955). Fig. 3 shows the scale and date of photographic coverage utilized in compiling the factor maps for the six study areas.

40. Before the air photos were studied, a mosaic was constructed on which the sample points for each factor family were located by the appropriate group. The factor values in terms of class ranges were assigned each site location. With this as a starting point, the various patterns on the photos were identified according to tone, texture, and geometry. Where the sample points occurred within a pattern, the class range for that pattern was extrapolated to similar patterns. For patterns without ground data, the terrain characteristics were assigned through associations of landforms, topographic position, and the interpreter's knowledge of the area. After all the identified patterns had been outlined and assigned a number or map unit symbol representing a factor value class, the outlines were transferred to the study area mosaics to obtain a regional view and to facilitate transfer to base maps.

41. The process varied in detail among the factor families, but the basic principles were common to all. Details of the photo-interpretation processes used for each factor family are given in Volumes II through V.

It was recognized at the inception of the project that the task of interpreting air photos in the quantitative terms required by the analytical performance prediction model would prove to be very difficult. In an effort to alleviate the difficulty, a special air-photo interpretation task was made an integral part of the MERS program. This task was performed by the Photographic Interpretation Research Division of CRREL and was directed at compiling a catalog of selected Thailand terrain features and describing them in such a manner that the information could be used in making estimates of their effects on the performance of ground vehicles. A secondary purpose of this study was to determine the effects of photo scale and film emulsions on the acquisition of terrain information. The original intent was to obtain new photographs that included large- and medium-scale air photos using three film emulsions. However, the delay in obtaining new photos made it necessary to use existing medium- and small-scale photos during the laboratory and field work. New large- and medium-scale photos obtained during the dry season were available for the Lop Buri area prior to the completion of this part of the study. Because of the limitations imposed by the acquisition of new photos, the study on comparative photography (scale and film emulsion) allowed only partial fulfillment of the objectives.

43. A catalog of terrain types as found primarily in two of the primary study areas is presented as Volume VI and is divided into five parts; four are concerned with terrain features associated with four factor families, and one with certain aspects of comparative photography. The terrain features associated with the factor families are arranged in the following order: surface composition, surface geometry, vegetation, and hydrologic geometry. The scheme of presenting a short text followed by air and ground photos, then field data, where available, is applied to each feature in all four terrain factor families. The text discusses the following aspects of photographic analysis: recognition on air photo, appearance on the ground, dimensions, relation to other factors, and regional distribution. Each aspect is considered with reference to the photographic pattern of specific features pertinent to the factor family in question. The illustrations consist of aerial mosaics followed by

stereopairs of air photos, ground photographs, sketches, and significant field data.

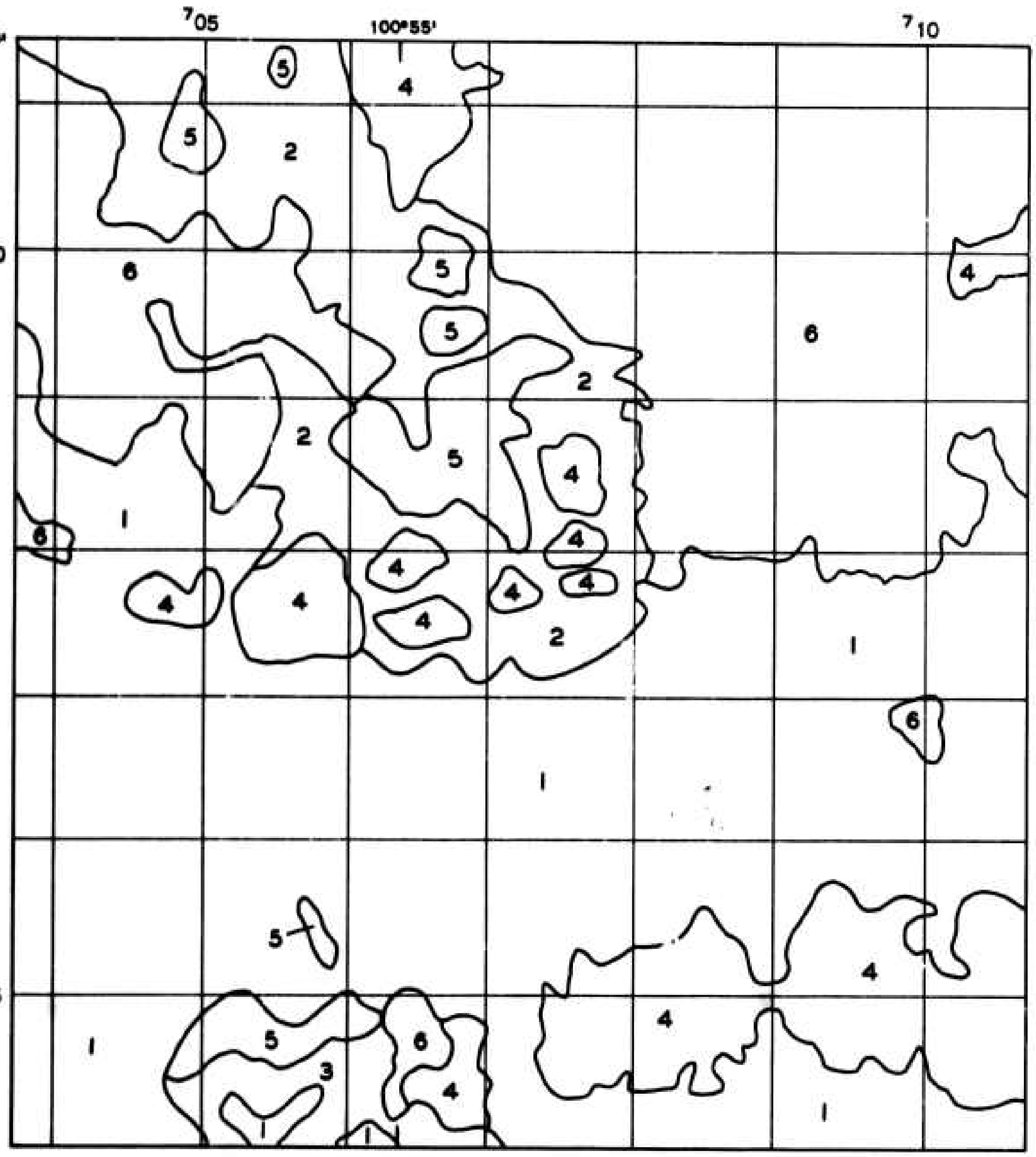
44. The catalog's limitations, which result from use of inadequate photography, are significant, and consequently, it should not be considered representative of the state-of-the-art. The catalog is, however, based on far more extensive and detailed ground truth data than were available to previous investigators in Thailand. It is likely that the general principles described in the catalog will have application to other Southeast Asian areas.

Compilation of Factor-Family Maps

Compilation process

45. After the various factor value classes had been delineated on the photomosaics, the lines between classes were transferred to base map sheets at a scale of 1:50,000. A slope factor map compiled in the manner described is shown in fig. 4. A total of 325 individual factor maps were prepared of the six study areas (table 4).

46. After all the factor maps of a particular factor family had been compiled, they were combined into factor-family maps. For example, the slope, obstacle spacing, terrain approach angle, and step height maps were superposed on a single base to produce a surface geometry factor-family map (fig. 5). Each area in the maps was identified by an array of four digits that represented map classes of each of the four factors in the above-listed sequence. To simplify the identification of factor-family units on a map, a number that represented factor class of the individual factors was assigned for each separate unit. In other words, in fig. 5 the number 153 indicates a slope map unit of 1 (0-1.5 deg), obstacle spacing class 5 (>45.7 m), approach angle class 5/5 (165 - <180 deg), and step height class 1/1 (0-10 cm). The fractional designation for approach angle and step height indicates that dual classes were mapped that were direction-dependent (see legend in fig. 5 for explanation). A total of 100 factor-family maps were prepared for the study areas.

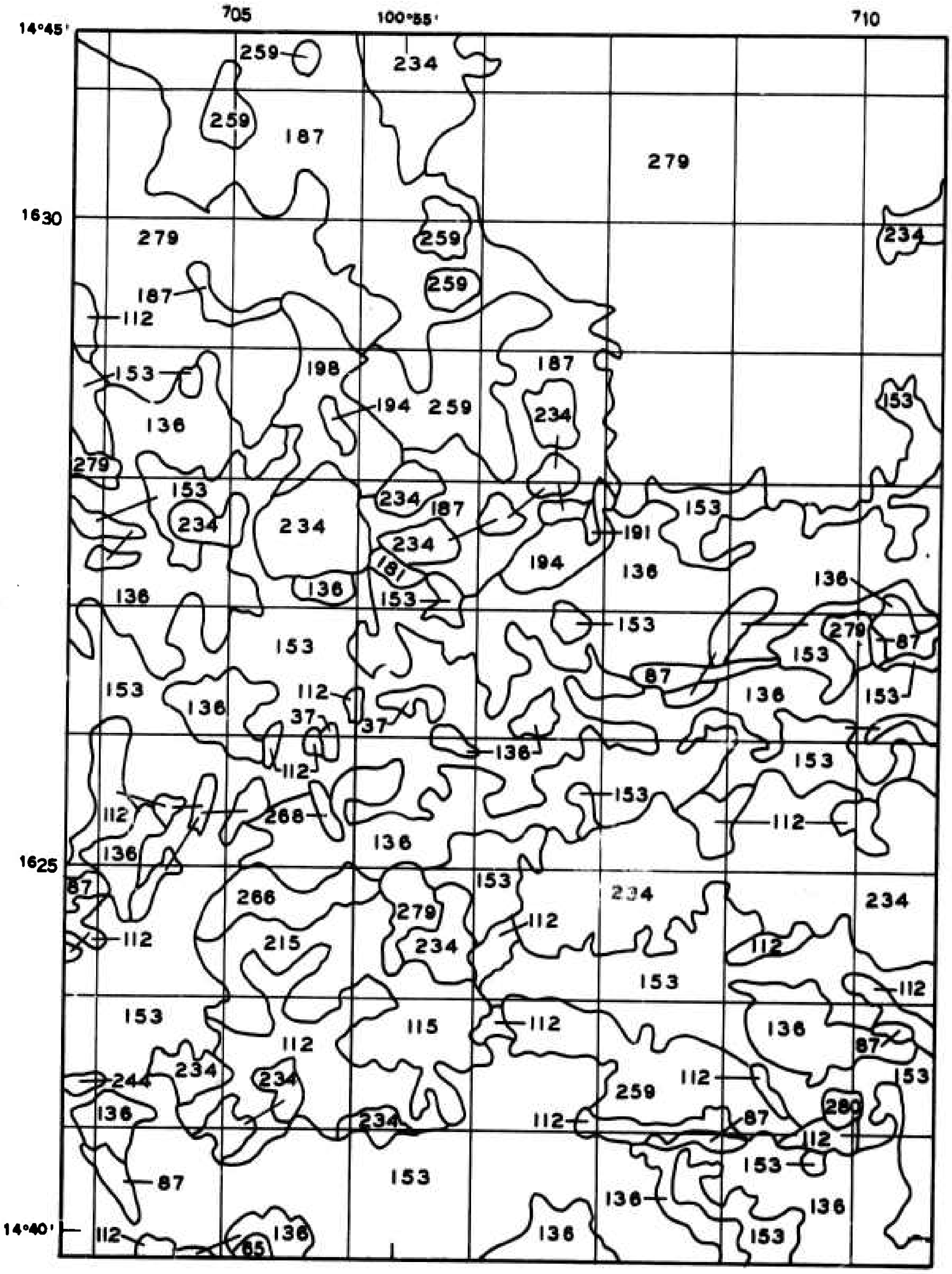


A portion of MERS Sheet LB III, Lop Buri study area

LEGEND

MAPPING CLASS	RANGE, DEG
1	0-1.5
2	> 1.5-4.5
3	> 4.5-9
4	> 9-18
5	> 18-30
6	> 30-45

Fig. 4. Example of slope factor



A portion of MERS Sheet LB III,
Lop Buri study area

Fig. 5. Example of a surface geometry factor-family

Map Unit*	SL†	OS	AA	SH	Map Unit*	SL†	OS
	1	2	3/3	3/3		1	4
	1	2	5/5	1/1		1	4
	1	3	2/2	1/1		1	4
	1	3	2/2	2/2		1	4
	1	3	2/2	3/3		1	4
	1	3	2/3	1/1		1	4
	1	3	2/3	2/2	65	1	4
	1	3	2/2	2/3		1	4
	1	3	2/3	3/2		1	4
	1	3	2/3	3/3		1	4
	1	3	2/3	4/4		1	4
	1	3	3/1	1/1		1	4
	1	3	3/1	2/2		1	4
	1	3	3/1	3/2		1	4
	1	3	3/2	2/2		1	4
	1	3	3/2	2/3		1	4
	1	3	3/2	3/3		1	4
	1	3	3/3	1/1		1	4
	1	3	3/3	2/2		1	4
	1	3	3/3	2/3	78	1	4
	1	3	3/3	3/2		1	4
22	1	3	3/3	3/3		1	4
	1	3	3/3	3/4		1	4
	1	3	3/3	4/3	82	1	4
	1	3	3/3	4/4	83	1	4
	1	3	3/3	5/4		1	4
	1	3	3/4	1/1		1	4
	1	3	3/4	3/2	86	1	4
	1	3	3/4	3/3	87	1	4
	1	3	3/4	3/4		1	4
	1	3	4/2	3/3		1	4
	1	3	4/4	1/1		1	4
	1	3	4/4	2/2		1	4
	1	3	4/4	3/3		1	4
	1	3	5/3	3/2	93	1	4
	1	3	5/3	3/3	94	1	4
37	1	3	5/5	1/1		1	4
	1	3	5/5	2/2		1	4
39	1	3	5/5	3/3		1	4
	1	4	1/1	1/1		1	4
	1	4	1/1	2/2		1	4
	1	4	1/2	1/1		1	4
	1	4	1/2	2/2	101	1	4
	1	4	1/2	3/3		1	4
	1	4	1/3	1/1		1	4
	1	4	1/3	2/2		1	4
	1	4	1/3	2/3		1	4
	1	4	1/3	2/5		1	4
	1	4	1/3	3/3	107	1	4
	1	4	2/1	1/1		1	4
	1	4	2/1	2/2		1	4
	1	4	2/2	1/1		1	4
	1	4	2/2	2/2		1	4
	1	4	2/2	2/3	112	1	4
	1	4	2/2	3/2	113	1	4
	1	4	2/2	3/3		1	4
	1	4	2/2	3/4		1	4
	1	4	2/2	4/3	116	1	4

Note: Blank areas are water bodies.

- * Each map unit represents an array of
below), vertical obstacle spacing OS,
were mapped. The numerator of the fra
easterly direction (i.e. azimuth from
> 180 to 360 deg) assuming that the ve

† Mapping class ranges of each surface

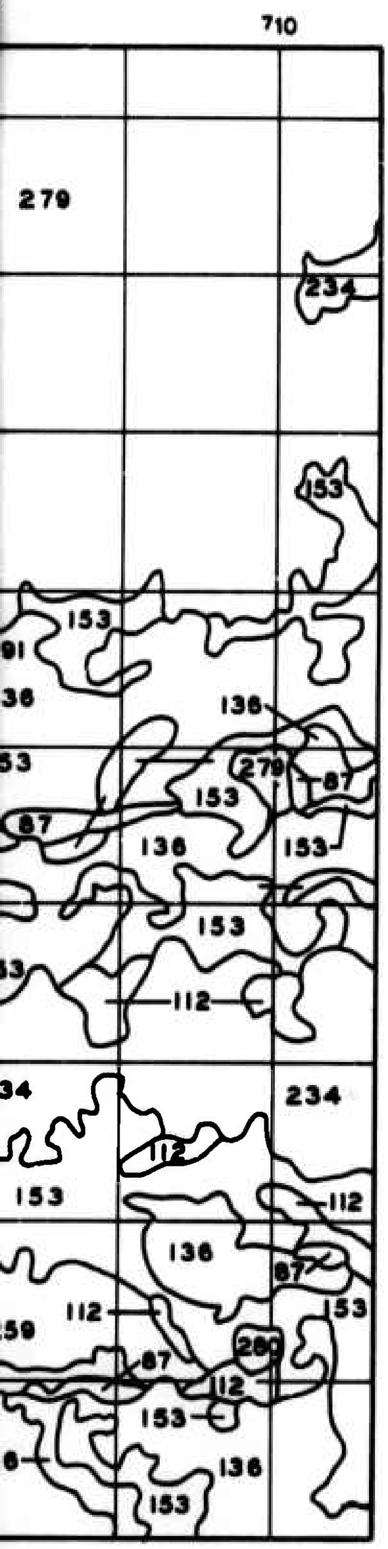
Slope (SL)

Mapping Class	Range deg
1	0-1.5
2	> 1.5-4.5
3	> 4.5-9
4	> 9-18
5	> 18-30
6	> 30-45
7	> 45

Mapping Class
1
2
3
4
5

Units do not occur on this

A.



LEGEND

Map Unit*	SL†	OS	AA	SH
	1	2	3/3	3/3
	1	2	5/5	1/1
	1	3	2/2	1/1
	1	3	2/2	2/2
	1	3	2/2	3/3
	1	3	2/3	1/1
	1	3	2/3	2/2
	1	3	2/2	2/3
	1	3	2/3	3/2
	1	3	2/3	3/3
	1	3	2/3	4/4
	1	3	3/1	1/1
	1	3	3/1	2/2
	1	3	3/1	3/2
	1	3	3/2	2/2
	1	3	3/2	2/3
	1	3	3/2	3/3
	1	3	3/3	1/1
	1	3	3/3	2/2
	1	3	3/3	2/3
	1	3	3/3	3/2
22	1	3	3/3	3/3
	1	3	3/3	3/4
	1	3	3/3	4/3
	1	3	3/3	4/4
	1	3	3/3	5/4
	1	3	3/4	1/1
	1	3	3/4	3/2
	1	3	3/4	3/3
	1	3	3/4	3/4
	1	3	4/2	3/3
	1	3	4/4	1/1
	1	3	4/4	2/2
	1	3	4/4	3/3
	1	3	5/3	3/2
	1	3	5/3	3/3
37	1	3	5/5	1/1
	1	3	5/5	2/2
39	1	3	5/5	3/3
	1	4	1/1	1/1
	1	4	1/1	2/2
	1	4	1/2	1/1
	1	4	1/2	2/2
	1	4	1/2	3/3
	1	4	1/3	1/1
	1	4	1/3	2/2
	1	4	1/3	2/3
	1	4	1/3	2/5
	1	4	1/3	3/3
	1	4	2/1	1/1
	1	4	2/1	2/2
	1	4	2/2	1/1
	1	4	2/2	2/2
	1	4	2/2	2/3
	1	4	2/2	3/2
	1	4	2/2	3/3
	1	4	2/2	3/4
	1	4	2/2	4/3

Map Unit*	SL†	OS	AA	SH
	1	4	2/2	5/5
	1	4	2/3	1/1
	1	4	2/3	1/2
	1	4	2/3	2/2
	1	4	2/3	2/3
	1	4	2/3	3/2
65	1	4	2/3	3/3
	1	4	2/3	3/4
	1	4	2/3	4/2
	1	4	2/3	4/3
	1	4	2/3	4/4
	1	4	2/4	2/2
	1	4	2/4	3/3
	1	4	3/1	2/2
	1	4	3/2	1/1
	1	4	3/2	2/2
	1	4	3/2	2/3
	1	4	3/2	2/5
	1	4	3/2	3/2
78	1	4	3/2	3/3
	1	4	3/2	3/4
	1	4	3/2	4/3
	1	4	3/2	4/4
82	1	4	3/3	1/1
83	1	4	3/3	2/2
	1	4	3/3	2/3
	1	4	3/3	2/4
86	1	4	3/3	3/2
87	1	4	3/3	3/3
	1	4	3/3	3/4
	1	4	3/3	4/2
	1	4	3/3	4/3
	1	4	3/3	4/4
	1	4	3/3	5/4
93	1	4	3/3	5/5
94	1	4	3/3	6/6
	1	4	3/4	1/1
	1	4	3/4	2/2
	1	4	3/4	2/3
	1	4	3/4	3/2
	1	4	3/4	3/3
	1	4	3/4	3/4
	1	4	3/4	5/5
	1	4	3/5	3/2
103	1	4	4/2	3/3
	1	4	4/3	2/2
	1	4	4/3	3/3
	1	4	4/3	4/3
107	1	4	4/4	1/1
	1	4	4/4	2/2
	1	4	4/4	3/2
	1	4	4/4	3/3
	1	4	5/3	2/4
112	1	4	5/5	1/1
113	1	4	5/5	2/2
	1	4	5/5	2/3
	1	4	5/5	3/2
116	1	4	5/5	3/3

Map Unit*	SL†	OS	AA	SH
117	1	4	5/5	5/5
	1	4	6/6	1/1
	1	5	1/1	1/1
	1	5	2/1	2/2
	1	5	2/2	1/1
	1	5	2/2	3/2
	1	5	2/2	3/3
	1	5	2/3	1/1
125	1	5	2/3	3/3
	1	5	2/3	4/3
	1	5	2/3	4/4
	1	5	2/4	3/3
	1	5	3/2	1/1
	1	5	3/2	3/2
	1	5	3/2	3/3
132	1	5	3/3	1/1
	1	5	3/3	2/2
	1	5	3/3	2/3
	1	5	3/3	3/2
136	1	5	3/3	3/3
	1	5	3/3	4/3
	1	5	3/3	6/5
	1	5	3/4	3/3
140	1	5	4/2	3/3
	1	5	4/3	3/3
	1	5	4/3	4/4
	1	5	4/3	5/6
	1	5	4/4	1/1
145	1	5	4/4	2/2
	1	5	4/4	3/2
	1	5	4/4	3/3
	1	5	4/4	3/6
	1	5	4/4	4/2
	1	5	4/6	5/4
	1	5	5/3	3/3
	1	5	5/4	5/7
153	1	5	5/5	1/1
154	1	5	5/5	2/2
	1	5	5/5	2/3
	1	5	5/5	3/2
157	1	5	5/5	3/3
	1	5	5/5	4/4
	1	5	5/5	5/4
	1	5	6/6	1/1
	1	5	6/6	4/4
	1	5	6/6	5/5
	1	5	8/1	6/6
	2	3	3/2	1/1
	2	3	3/3	1/1
	2	3	3/3	3/3
167	2	3	5/5	1/1
	2	4	2/2	1/1
	2	4	2/2	2/3
	2	4	1/3	1/1
	2	4	2/3	2/2
	2	4	2/3	3/3
	2	4	2/3	4/3
	2	4	3/2	2/2

Map Unit*	SL†	OS	AA	SH
	2	4	3/2	3/3
	2	4	3/2	4/3
177	2	4	3/3	1/1
	2	4	3/3	2/2
	2	4	3/3	2/4
180	2	4	3/3	3/2
181	2	4	3/3	3/3
	2	4	3/3	4/3
	2	4	3/4	3/4
	2	4	4/4	1/1
	2	4	4/4	2/2
	2	4	4/4	3/3
187	2	4	5/5	1/1
	2	4	5/5	2/2
189	2	4	5/5	3/3
	2	5	3/2	3/3
191	2	5	3/3	1/1
	2	5	3/3	2/2
193	2	5	3/3	3/2
194	2	5	3/3	3/3
	2	5	4/4	1/1
	2	5	4/4	2/2
	2	5	4/4	3/3
198	2	5	5/5	1/1
	2	5	5/5	2/2
	2	5	5/5	2/3
201	2	5	5/5	3/3
	2	5	5/5	5/5
	3	3	2/3	1/1
	3	3	5/5	1/1
	3	4	2/2	1/1
	3	4	2/2	3/3
	3	4	2/3	1/1
	3	4	2/3	2/2
	3	4	2/3	3/3
	3	4	3/3	1/1
	3	4	3/3	2/2
	3	4	3/3	3/3
	3	4	4/4	1/1
	3	4	4/4	2/2
215	3	4	5/5	1/1
	3	4	5/5	2/2
	3	4	5/5	3/3
	3	5	3/3	1/1
	3	5	3/3	3/3
	3	5	4/4	1/1
	3	5	4/4	2/2
	3	5	5/5	1/1
	3	5	5/5	2/2
	3	5	5/5	3/3
	3	2	4/4	2/2
	4	3	2/3	2/2
	4	3	2/3	2/3
	4	3	2/3	3/3
	4	3	4/4	2/2
	4	4	2/2	2/3
	4	4	3/3	2/2
	4	4	3/3	3/3

Map Unit*	SL†	OS	AA	SH
	4	4	4/4	1/1
234	4	4	4/4	2/2
	4	4	4/4	3/3
236	4	4	5/5	1/1
	4	4	5/5	2/2
	4	4	5/5	3/3
	4	5	2/2	1/1
	4	5	3/3	1/1
	4	5	3/3	2/2
	4	5	3/3	3/3
	4	5	4/4	1/1
244	4	5	4/4	2/2
	4	5	4/4	3/2
	4	5	4/4	3/3
	4	5	5/5	1/1
	4	5	5/5	2/2
	5	3	2/2	2/2
	5	3	2/3	2/2
	5	3	2/3	3/3
	5	3	3/3	3/3
	5	3	5/5	2/2
	5	4	2/2	1/1
	5	4	2/2	2/2
	5	4	3/3	2/2
	5	4	3/3	3/3
	5	4	4/4	1/1
259	5	4	4/4	2/2
	5	4	4/4	3/3
261	5	4	5/5	1/1
	5	4	5/5	3/3
	5	5	3/3	2/2
	5	5	3/3	3/3
	5	5	4/4	1/1
266	5	5	4/4	2/2
	5	5	4/4	3/2
268	5	5	4/4	3/3
	5	5	4/4	4/4
	5	5	5/5	1/1
	5	5	5/5	2/2
	6	3	3/3	3/3
	6	3	2/2	3/3
	6	3	2/3	3/3
	6	3	3/3	3/3
	6	3	5/5	2/2
277	6	4	3/3	1/1
	6	4	3/3	2/2
279	6	4	3/3	3/3
280	6	4	4/4	2/2
	6	4	4/4	3/3
	6	4	5/5	1/1
	6	4	5/5	3/3
284	6	5	3/3	3/3
	6	5	4/4	3/3
	6	5	5/5	1/1
	6	5	5/5	2/2
	6	5	5/5	3/3

Note: Blank areas are water bodies.

* Each map unit represents an array of four symbols (i.e. 1, 2, 3/3, 3/3) indicating mapping classes of slope SL (see diagram below), vertical obstacle spacing OS, approach angle AA, and step height SH. Fractional designations indicate that dual classes were mapped. The numerator of the fraction indicates class range that will be encountered while traversing an area in an easterly direction (i.e. azimuth from > 0 to 180 deg) and the denominator refers to a westerly direction (i.e. azimuth from > 180 to 360 deg) assuming that the vehicle intersects the obstacle at a right angle.

† Mapping class ranges of each surface geometry factor are:

Slope (SL)

Mapping Class	Range deg
1	0-1.5
2	> 1.5-4.5
3	> 4.5-9
4	> 9-18
5	> 18-30
6	> 30-45
7	> 45

Vertical Obstacle Spacing (OS)

Mapping Class	Range ft	Range m
1	0-7	0-2.1
2	> 7-12	> 2.1-3.7
3	> 12-50	> 3.7-15.2
4	> 50-150	> 15.2-45.7
5	> 150	> 45.7

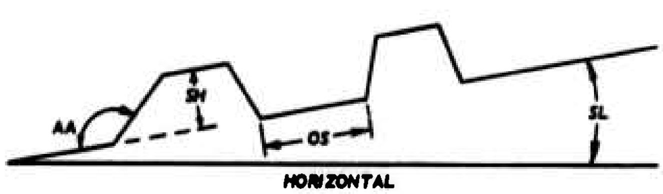
Approach Angle (AA)

Mapping Class	Range deg
1	< 100
2	100-< 125
3	125-< 150
4	150-< 165
5	165-< 180
6	180-< 200
7	200-< 210
8	210-< 220
9	≥ 220

Step Height (SH)

Mapping Class	Range in.	Range cm
1	0-4	0-10
2	> 4-10	> 10-25
3	> 10-18	> 25-46
4	> 18-30	> 46-76
5	> 30-48	> 76-122
6	> 48-66	> 122-168
7	> 66-84	> 168-213
8	> 84	> 213

⊠ Units do not occur on this map.



B III,

y factor-family

B.

Construction of new base maps

47. The factor-family maps are presented on base sheets at a scale of 1:50,000 taken from the Army Map Service (AMS) Series L-708. The limits of these maps do not in all instances coincide with those of the AMS sheets because new base sheets were made, where needed, to reduce the number of partially mapped sheets (fig. 6). In most cases, these limit changes involved shifting the latitude or longitude 5 or 10 min from those of the AMS sheets. Preparation of new base sheets resulted in a reduction of the total number of base sheets that covered the six study areas from 32 to 25. Since four factor families are involved, this resulted in an overall reduction of 28 maps.

Factor-Complex Maps for Ground Mobility

48. There are two prerequisites to predicting and portraying the effects of terrain on ground mobility in an area: (a) identification of the total range of terrain factor values in a given area, and (b) knowledge of the degree of effects imposed by various combinations of the terrain factor values acting in concert. The first requirement is dealt with in Volume VII of this report, and the second requirement is covered in another WES report.*

49. The method used in this study to portray the terrain was to synthesize the factor-family maps into a factor-complex map. The procedure for compiling a factor-complex map is to overlay the surface geometry, surface composition, and vegetation factor-family maps in that order. After the three maps have been superposed, the areas outlined have an array of three numbers identifying the factor value class combinations of surface geometry, surface composition, and vegetation factor classes in that order. To simplify the identification of factor complexes, these arrays are tabulated and a number is assigned to each different array. These numbers are then substituted on the final map in the appropriate outlined area.

---

* U. S. Army Engineer Waterways Experiment Station, CE, "An Analytical Model for Predicting Cross-Country Vehicle Performance," Technical Report No. 3-783 (in preparation), Vicksburg, Miss.

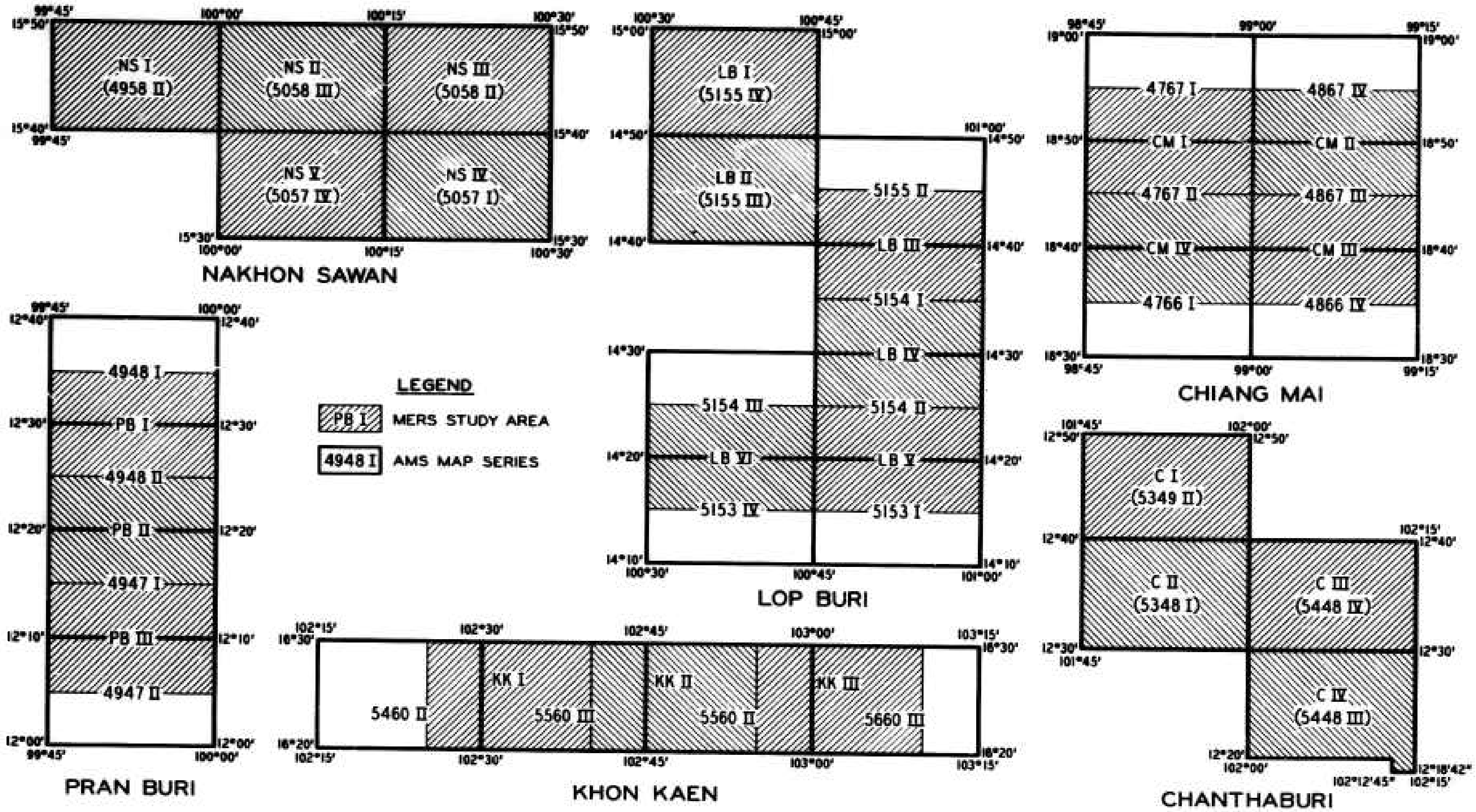


Fig. 6. Relation of MERS and AMS map quadrangles

50. It is, of course, not absolutely necessary to go through the intermediate stage of compiling factor-family maps. The factor-complex map can be compiled directly from the individual factor maps. However, the stage-by-stage process described above is much more convenient for manual compilation procedures.

51. Because of the mapping scale, the hydrologic geometry and linear surface geometry features are portrayed as linear symbols on factor-family maps. The surface geometry, surface composition, and vegetation factor-family maps are areal delineations. Therefore, to avoid mixing areal and linear designations on the same map, two distinct factor-complex maps were compiled. The areal delineations were synthesized into one factor-complex map as discussed in the preceding paragraph. The second factor-complex map is a synthesis of the linear features with the surface composition and vegetation factor-family characteristics along these lines in that order. The method of synthesis is the same for linear outlines as it is for areal outlines.

52. Plates 1 and 2 are examples of preliminary factor-complex maps; that is, maps on which a selected set of factors have been compiled from the simple factor maps as a convenient step in the compilation of the full factor-family maps (plate 3). Preliminary factor-complex maps are not constructed in every case; they are normally used only to simplify the bookkeeping during the compilation process. Plates 3 through 6 are examples of the completed factor-family maps; and plates 7 and 8 are examples of the final compilation, the areal and linear factor-complex maps, respectively, of the same area. Plates 7 and 8 delineate and identify every combination of all cross-country mobility factors (table 1) that occur in the mapped area.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

53. Some general conclusions that were drawn from the effort to develop a quantitative terrain description system for ground-locomotion analysis are presented below.

- a. The description of terrain in a form suitable as input for an analytical or mathematical method of predicting cross-country vehicle performance requires that the terrain be described in quantitative terms; a mathematical expression will not accept qualitative information.
- b. A description of terrain in quantitative terms presupposes the existence of an analytical or mathematical model of the activity or machine that relates terrain attributes to performance; only in this way can the significant terrain factors be reliably isolated.
- c. Quantitative data of the form required can be acquired by ground sampling, but the procedure is expensive and time consuming.
- d. It is practicable to obtain reasonably reliable estimates of the required factor values (or factor value classes) by photo interpretation.
- e. The accuracy of the factor values obtained by photo interpretation is strongly influenced by the scale, quality, and age of air photos.
- f. Construction of factor maps and factor-complex maps is a practical method of converting terrain data into a presentation that is suitable for cross-country mobility analysis.

Recommendations

54. Although experience with the development of the factor maps and with the construction of factor-family and factor-complex maps has demonstrated the general feasibility and utility of the concepts involved, it is apparent that the procedure in its present form is by no means a final solution to the problem. However, it is probably true that the terrain description system as presented herein is commensurate in reliability and degree of sophistication with the present state-of-the-art of vehicle

performance prediction. Also, it can be confidently anticipated that the locomotion prediction model will rapidly become more sophisticated, and this almost certainly implies that the terrain analysis and description processes must also be made capable of acquiring and portraying more detailed and reliable terrain data. The following recommendations are made in an effort to point the way to such refinements.

a. An effort should be made to develop more sophisticated instruments for use by field teams. Especially needed are recording instruments to reduce the number of personnel required in the field teams, to reduce the time spent per sample site, and to reduce the interface errors that accumulate in transcribing information from one format to another (e.g., field notebook to magnetic tape).

b. The problem involved in photo interpretation should be investigated, with the aim of making the process faster and more reliable. It is suggested that a more sophisticated and quantitative method of describing images is needed along with a more fundamental understanding of the relations between photo images and the ground conditions that they symbolize. This research should be conducted in such a way that ground truth data are taken at the instant of photography from the air, so that ground condition, reflectivity and emission properties, and photo imagery can be interrelated and understood.

c. The compilation process by which factor-complex maps are produced from the aggregation of individual factor maps should be reduced to a completely automated process. The manual compilation process used at the present time is much too laborious and time consuming to be used on any mapping problem involving really large areas.

d. The factors chosen for portrayal should be reassessed at relatively short intervals, to ensure that the terrain descriptions remain abreast of mathematical model development. It is likely that future versions of the vehicle performance prediction models will require additional factors as input; the description system must automatically include these in order to meet the requirements of mobility analysis.

e. Additional areas of the world, characterized by different climatic regimes and terrain conditions, should be studied and mapped, both to ensure that the description system is actually universally applicable, and to provide a wider range of conditions for consideration as design parameters for new vehicles. It is suggested that, at a minimum, areas should be selected in a desert, a tropical savannah, a temperate farm and forest, and a subarctic region.

Table 1

Terrain Factors Required by Project MERS Vehicle Performance Prediction Model

Factor Family	Factor
Surface geometry	Topographic slope*
	Step height (of vertical obstacles)*
	Approach angle (of vertical obstacles)*
	Vertical obstacle spacing*
Surface composition	Shear strength of soil at zero normal load (a_{ur}) (at surface)
	Angle of internal friction of soil (α_{ur}) (at surface)
	Rating cone index (soil mass strength)
Vegetation	Spacing of plant stems $\leq$ 2 in. in diam
	Spacing of plant stems $\leq$ 5 in. in diam
	Spacing of plant stems $\leq$ 9 in. in diam
	Spacing of plant stems $\leq$ 50 in. in diam
	Spacing of plant stems $\geq$ 1 in. in diam
	Spacing of plant stems $\geq$ 3 in. in diam
	Spacing of plant stems $\geq$ 6 in. in diam
	Spacing of plant stems $\geq$ 10 in. in diam
Hydrologic geometry	Contact approach angle (of water-land interface)**
	Step height (of water-land interface)**
	Position of step base (of water-land interface)**
	Water depth**

* See fig. 5 for illustration.
** See plate 6 for illustration.

Table 2

Data Collection Sites in Thailand

Study Area	Factor Family Sites: Surface Composition	Surface Geometry	Vegetation	Hydrologic Geometry	Total
Nakhon Sawan	71	60	39	46	216
Lop Buri	171	165	35	81	452
Chiang Mai	87	167	54	125	433
Pran Buri	75	120	50	99	344
Khon Kaen	80	300	76	133	589
Chanthaburi	94	112	42	105	353
Total	578	924	296	589	2387

Table 3

Terrain Factors Affecting Vehicle Performance

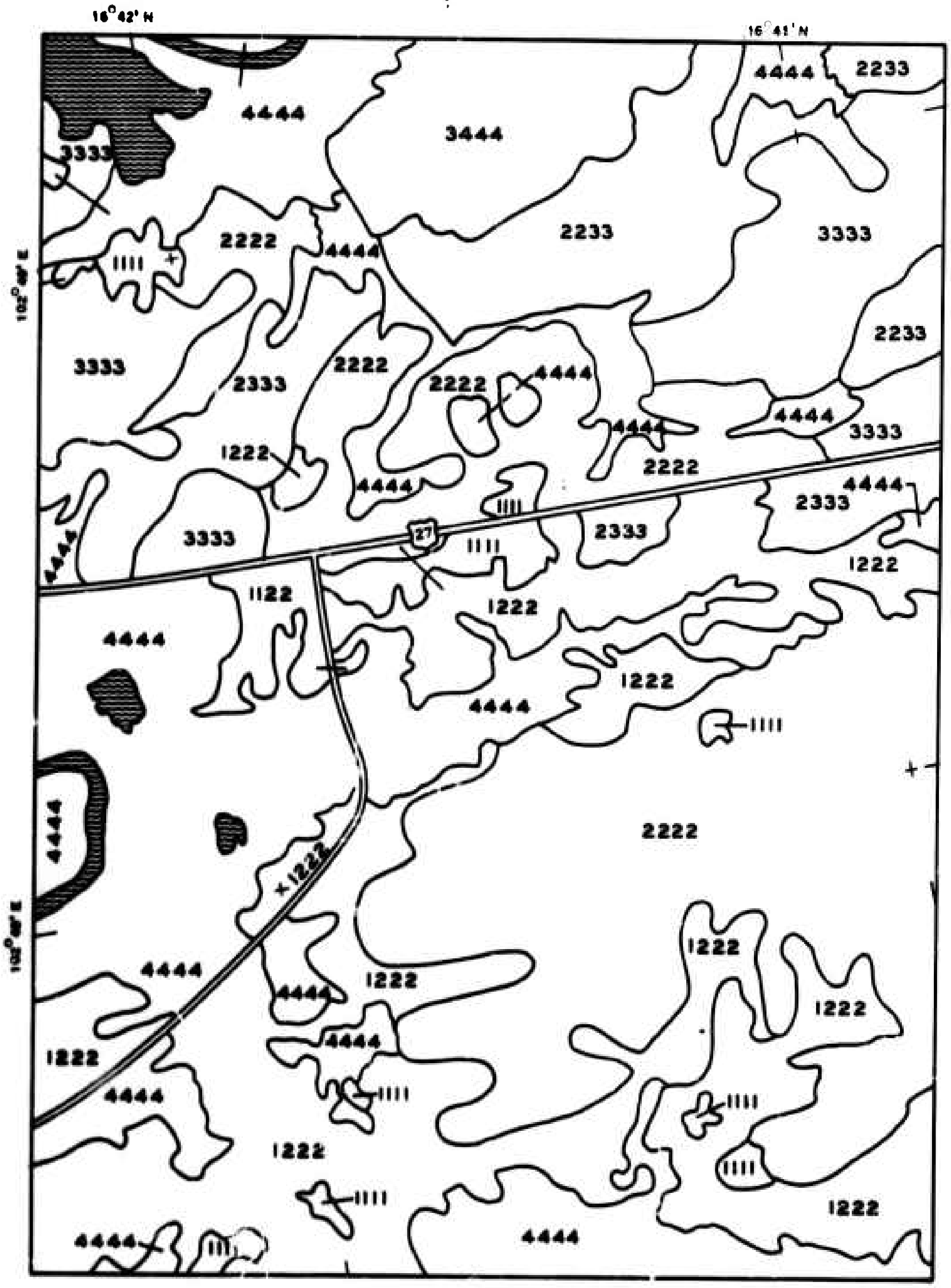
Terrain Factor Family	Terrain Factor	Unit of Measure	Class Ranges 1	2	3	4	5	6	7	8	9
Surface composition*	Soil mass strength	RCI	<10	10-25	>25-60	>60-100	>100				
	Soil surface strength: a_{ur}	kg/cm^2 psi	0-0.07 0-1	>0.07-0.14 >1-2	>0.14-0.28 >2-4	0-0.07 0-1	>0.07-0.14 >1-2	>0.14-0.28 >2-4	0-0.07 0-1	>0.07-0.14 >1-2	>0.14-0.28 >2-4
	α_{ur}	deg	0-10	0-10	0-10	>10-20	>10-20	>10-20	>20-40	>20-40	>20-40
Surface geometry	Slope	deg	0-1.5	>1.5-4.5	>4.5-9	>9-18	>18-30	>30-45	>45		
	Vertical obstacle spacing	m ft	0-2.1 0-7	>2.1-3.7 >7-12	>3.7-15.2 >12-50	>15.2-45.7 >50-150	>45.7 >150				
	Terrain approach angle	deg	<100	100-<125	125-<150	150-<165	165-<180	180-<200	200-<210	210-<220	≥220
	Step height	cm in.	0-10 0-4	>10.2-25 >4-10	>25-46 >10-18	>46-76 >18-30	>76-122 >30-48	>122-168 >48-66	>168-213 >66-84	>213 >84	
Vegetation**	Spacing of stems ≤ 2, 5, 9, and 50 in. in diameter	m ft	>9.1 >30	>3.0-9.1 >10-30	>1.5-3.0 >5-10	0-1.5 0-5					
	Spacing of stems ≥ 1, 3, 6, and 10 in. in diameter	m ft	>9.1 >30	>3.0-9.1 >10-30	>1.5-3.0 >5-10	0-1.5 0-5					
Hydrologic geometry†	Contact approach angle	deg	<145	145-155	>155-165	>165-180					
	Step height††	cm in.	<30 <12	30-<61 12-<24	61.0-<91 24-<36	91.4-122 36-48	>122 >48				
	Position of step base‡	cm in.	>122 >48	>91-122 >36-48 bwl‡‡	>46-91 >18-36 bwl	3-46 1-18 bwl	At water level	3-30 1-12 awl§	>30-76 >12-30 awl	>76-122 >30-48 awl	>122 >48 awl
	Water depth	m ft	0.9-1.4 3-4.5	>1.4 >4.5							

* Maximum and minimum moisture conditions mapped.
** Class ranges for each diameter are mapped.
† Considered a surface geometry feature when water depth is <3 ft (<0.9144 m). Mean maximum and minimum water depth mapped.
†† Step is a slope change >35 deg.
‡ Referenced to water level.
‡‡ Below water level.
§ Above water level.

Table 4

Tabulation of Factor Maps Prepared

Study Area	Maps Covering Study Area	Factor Maps Prepared for: Surface Composition	Surface Geometry	Vegetation	Hydrologic Geometry	Total
Nakhon Sawan	5	15	20	10	20	65
Lop Buri	6	18	24	12	24	78
Chiang Mai	4	12	16	8	16	52
Pran Buri	3	9	12	6	12	39
Khon Kaen	3	9	12	6	12	39
Chanthaburi	4	12	16	8	16	52
Total	25	75	100	50	100	325



NOTE: ALL FACTORS WERE DRAWN FROM VEGETATION FACTOR FAMILY

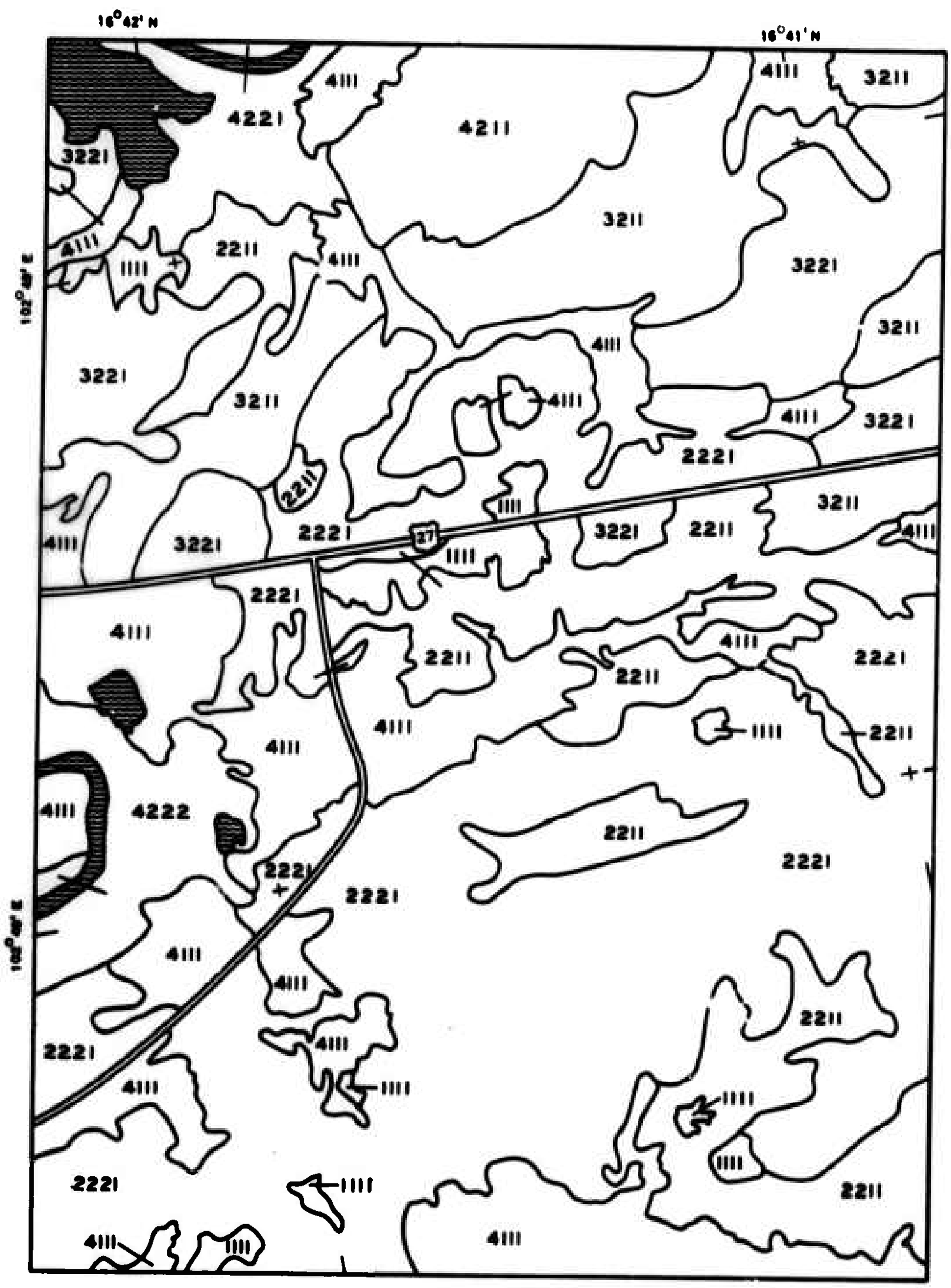
EXAMPLE OF
A PRELIMINARY
FACTOR-COMPLEX MAP
SPACING CLASSES FOR
STEMS ≤ 2, 5, 9, AND 50 IN.

PLATE 1 (1 of 2 sheets)

LEGEND

Each array of four symbols (i.e. 1, 1, 1, 1) indicates spacing classes for stems $\leq$ 2, 5, 9, and 50 in. ($\leq$ 5, 13, 23, and 127 cm), always designated in that order. The class ranges are:

Mapping Class	Range	
	ft	m
1	> 30	> 9.1
2	> 10-30	> 3.0-9.1
3	> 5-10	> 1.5-3.0
4	0-5	0-1.5



NOTE: ALL FACTORS WERE DRAWN FROM VEGETATION FACTOR FAMILY

EXAMPLE OF A PRELIMINARY FACTOR-COMPLEX MAP

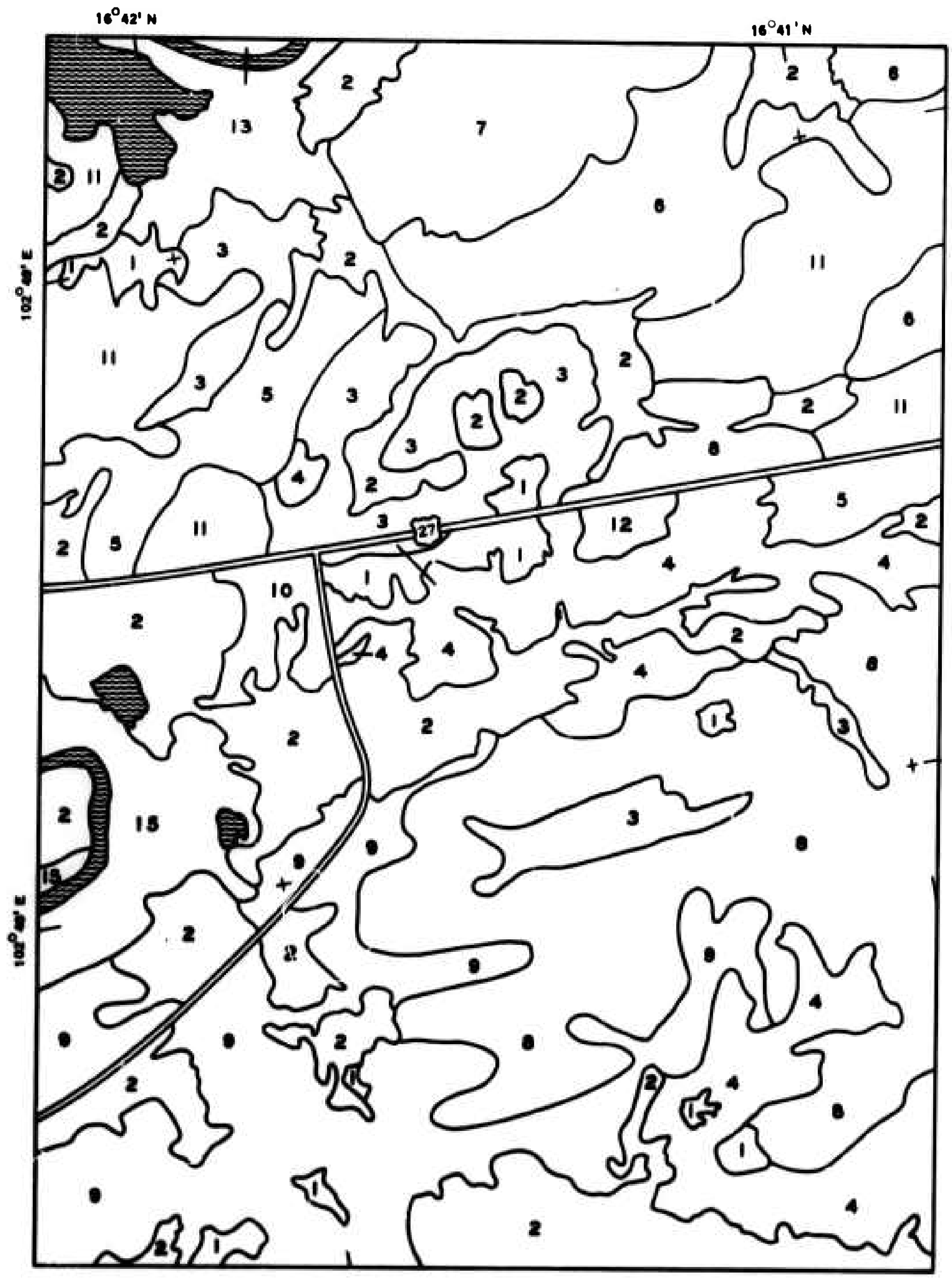
SPACING CLASSES FOR STEMS ≤ 1, 3, 6, AND 10 IN.

PLATE 2 (1 of 2 sheets)

LEGEND

Each array of four symbols (i.e. 1, 1, 1, 1) indicates spacing classes for stems $\geq$ 1, 3, 6, and 10 in. ($\geq$ 3, 8, 15, and 25 cm), always designated in that order. The class ranges are:

Mapping Class	Range	
	ft	m
1	> 30	> 9.1
2	> 10-30	>3.0-9.1
3	> 5-10	>1.5-3.0
4	0-5	0-1.5



EXAMPLE OF
VEGETATION
FACTOR-FAMILY MAP

PLATE 3 (1 of 2 sheets)

LEGEND

Arrays of Spacing Classes for Stems ≤ and ≥ the Specified Diameter								
	≤				≥			
Map Unit*	2 in. (5 cm)	5 in. (13 cm)	9 in. (23 cm)	50 in. (127 cm)	1 in. (3 cm)	3 in. (8 cm)	6 in. (15 cm)	10 in. (25 cm)
1	1	1	1	1	1	1	1	1
2	4	4	4	4	4	1	1	1
3	2	2	2	2	2	2	1	1
4	1	2	2	2	2	2	1	1
5	2	3	3	3	3	2	1	1
6	2	2	3	3	3	2	1	1
7	3	4	4	4	4	2	1	1
8	2	2	2	2	2	2	2	1
9	1	2	2	2	2	2	2	1
10	1	1	2	2	2	2	2	1
11	3	3	3	3	3	2	2	1
12	2	3	3	3	3	2	2	1
13	4	4	4	4	4	2	2	1
14	4	4	4	4	4	3	2	1
15	4	4	4	4	4	2	2	2

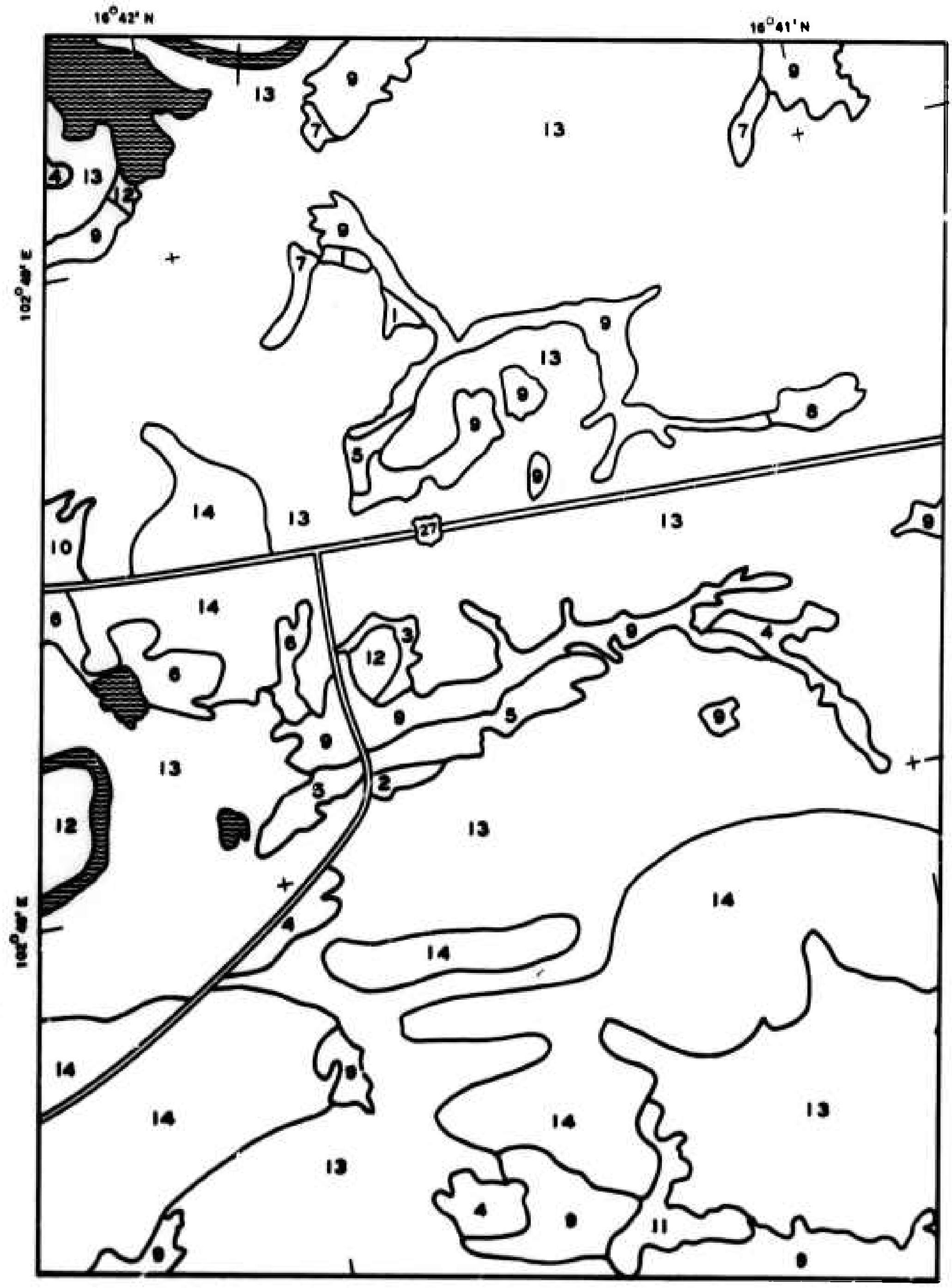
Note: Blank areas are unvegetated water bodies.
* Each map unit represents an array of eight symbols (i.e. 1, 1, 1, 1, 1, 1, 1, 1) indicating spacing classes for stems ≤ 2, 5, 9, and 50 in. (≤ 5, 13, 23, and 127 cm) and ≥ 1, 3, 6, and 10 in. (3, 8, 15, and 25 cm).

Mapping class ranges for each spacing class are:

Stem Spacing

Mapping Class	Range	
	ft	m
1	> 30	> 9.1
2	> 10-30	> 3.0-9.1
3	> 5-10	> 1.5-3.0
4	0-5	0-1.5

PLATE 3 (2 of 2 sheets)



EXAMPLE OF
SURFACE GEOMETRY
FACTOR-FAMILY MAP

PLATE 4 (1 of 2 sheets)

LEGEND

Map Unit*	SL**	OS	AA	SH	Map Unit*	SL**	OS	AA	SH
1	1	3	2/3	3/4	8	1	4	3/2	4/3
2	1	3	2/3	3/5	9	1	4	3/3	3/3
3	1	3	3/2	4/3	10	1	4	3/3	3/4
4	1	3	3/3	3/3	11	1	5	3/3	3/3
5	1	3	3/3	3/4	12	1	5	5/5	1/1
6	1	3	3/3	4/3	13	2	5	5/5	1/1
7	1	4	2/3	3/4	14	3	5	5/5	1/1

Note: Blank areas are water bodies.

* Each map unit represents an array of four symbols (i.e. 1, 2, 3/3, 3/3) indicating mapping classes of slope SL (see diagram below), vertical obstacle spacing OS, approach angle AA, and step height SH. Fractional designations indicate that dual classes were mapped. The numerator of the fraction indicates class range that will be encountered while traversing an area in an easterly direction (i.e. azimuth from > 0 to 180 deg) and the denominator refers to a westerly direction (i.e. azimuth from > 180 to 360 deg) assuming that the vehicle intersects the obstacle at a right angle.

** Mapping class ranges of each surface geometry factor are:

Slope (SL)

Mapping Class	Range deg
1	0-1.5
2	> 1.5-4.5
3	> 4.5-9
4	> 9-18
5	> 18-30
6	> 30-45
7	> 45

Vertical Obstacle Spacing (OS)

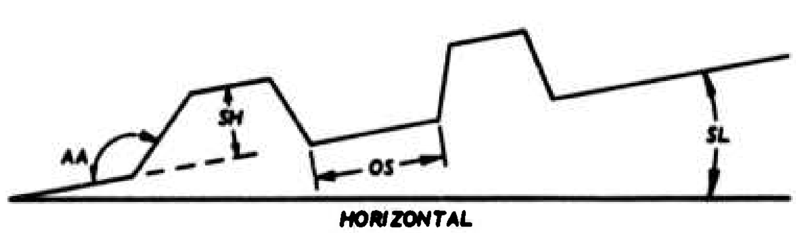
Mapping Class	Range ft	Range m
1	0-7	0-2.1
2	> 7-12	> 2.1-3.7
3	> 12-50	> 3.7-15.2
4	> 50-150	> 15.2-45.7
5	> 150	> 45.7

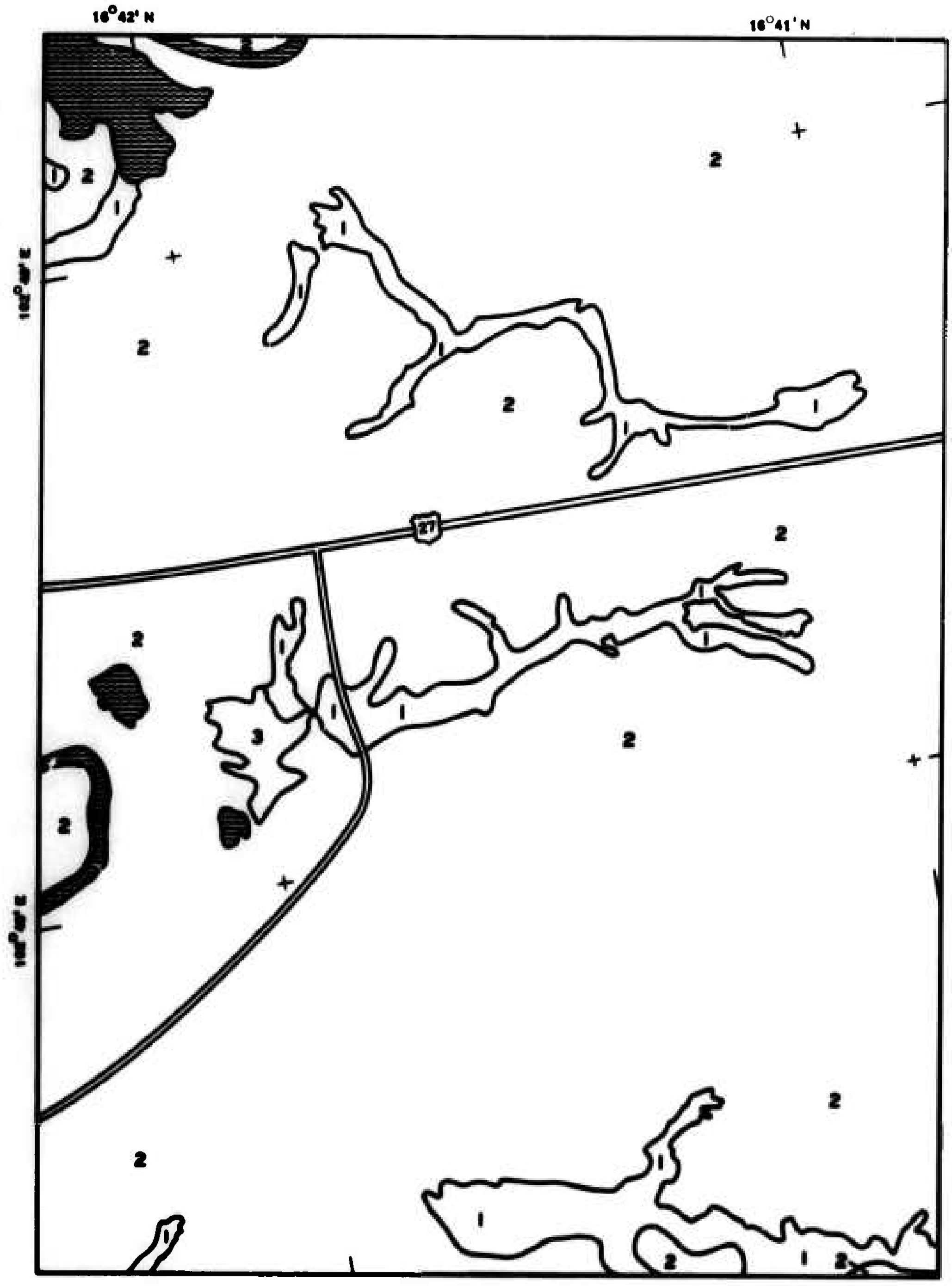
Approach Angle (AA)

Mapping Class	Range deg
1	< 100
2	100-< 125
3	125-< 150
4	150-< 165
5	165-< 180
6	180-< 200
7	200-< 210
8	210-< 220
9	≥ 220

Step Height (SH)

Mapping Class	Range in.	Range cm
1	0-4	0-10
2	> 4-10	> 10-25
3	> 10-18	> 25-46
4	> 18-30	> 46-76
5	> 30-48	> 76-122
6	> 48-66	> 122-168
7	> 66-84	> 168-213
8	> 84	> 213





EXAMPLE OF SURFACE COMPOSITION FACTOR-FAMILY MAP

PLATE 5 (1 of 2 sheets)

LEGEND

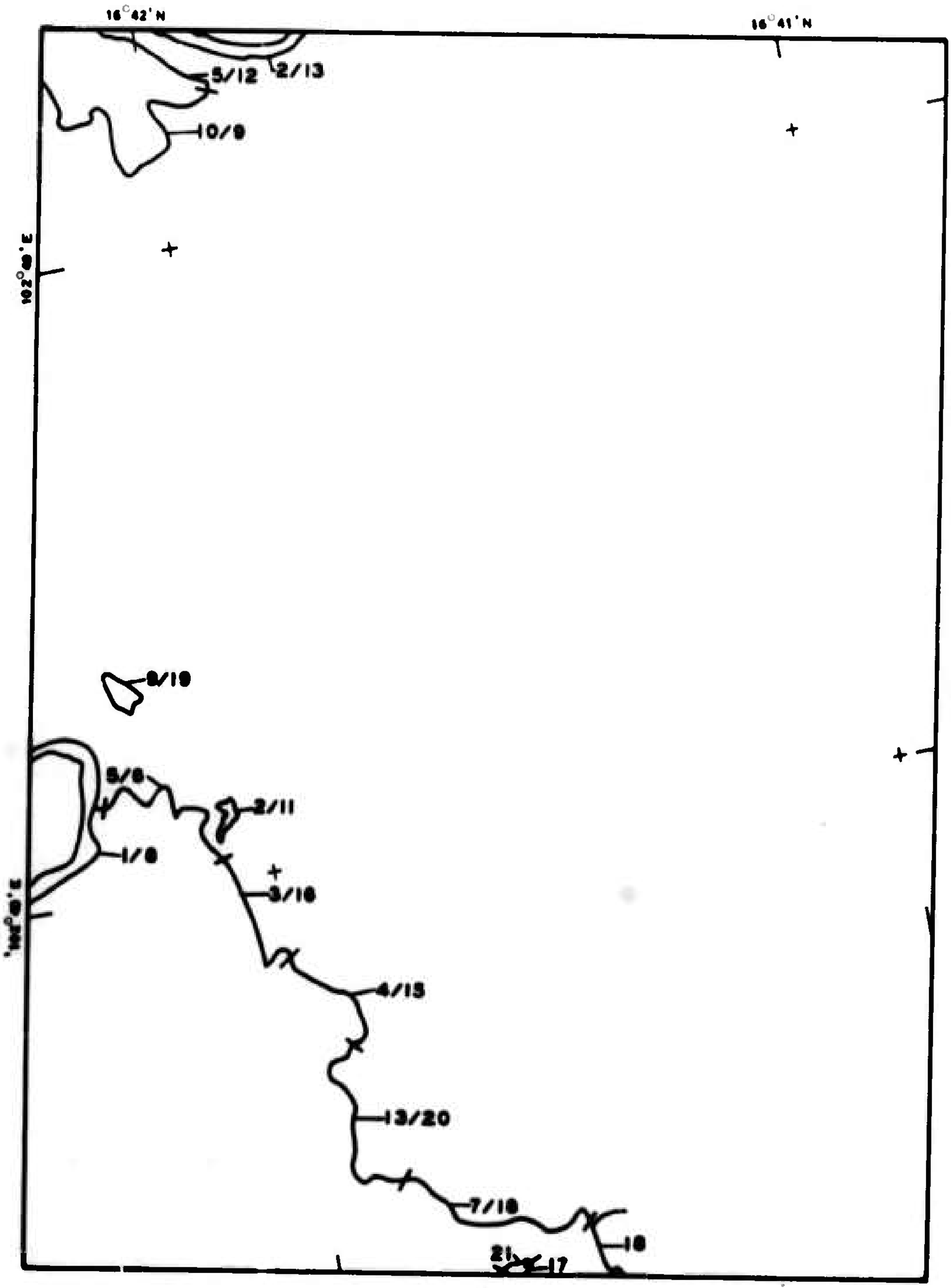
Unit	Soil Mass Strength: Maximum Moisture RCI	Soil Mass Strength: Minimum Moisture RCI	Soil Surface Strength: Maximum Moisture a_{ur} psi	a_{ur} kg/cm^2	α_{ur} deg	Minimum Moisture a_{ur} psi	a_{ur} kg/cm^2	α_{ur} deg	Conditions Where Maximum a_{ur} Occurs: a_{ur} psi	a_{ur} kg/cm^2	α_{ur} deg
1	25-60*	> 100	0-1	0-0.07	>10-20	0-1	0-0.07	> 20-40	> 2-4	> 0.14-0.28	> 20-40
2	> 50-100*	> 100	0-1	0-0.07	>10-20	0-1	0-0.07	> 20-40	> 1-2	> 0.07-0.14	> 10-20
3	Complex of > 60-100 and > 100	> 100	0-1	0-0.07	>10-20	0-1	0-0.07	> 20-40	Minimum moisture conditions		

Note: Blank areas are water bodies.

a_{ur} Shear strength at zero normal load.

α_{ur} Angle of internal friction.

* Maximum moisture has less than 30 percent probability of occurrence during the wet season. Lowest strengths commonly observed are 60-100 for unit 1; more than 100 for unit 2.



EXAMPLE OF
HYDROLOGIC GEOMETRY
FACTOR-FAMILY MAP

PLATE 6 (1 of 2 sheets)

LEGEND

Map Unit*	Hydrologic Geometry						
	West Bank			East Bank			
	AA	SH	PB	AA	SH	PB	WD
1	1	0	0	1	0	0	2
2	2	0	0	2	0	0	2
3	2	1	5	2	1	4	1
4	2	3	5	2	3	5	1
5	2	3	5	2	1	5	2
6	2	3	8	2	3	8	1
7	2	4	3	2	4	3	1
8	2	5	2	1	0	0	2
9	1	0	0	1	0	0	1
10	3	0	0	1	0	0	2
11	3	2	7	3	2	7	1
12	3	3	7	2	3	7	1
13	3	4	5	3	4	5	1

Map Unit	Surface Geometry					
	West Bank			East Bank		
	EA	IA	SH	IA	EA	SH
15	6	3	5	3	6	5
16	6	3	5	2	7	5
17	6	4	4	4	6	4
18	6	4	5	4	6	5
19	6	5	5	5	6	5
20	7	1	5	3	7	5
21	9	1	0	1	9	0

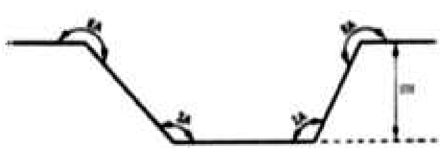
* Features are usually identified by a fraction. Each component of the fraction is a map unit that represents an array of seven symbols or less describing a particular feature. The numerator indicates high-water conditions and the denominator indicates low-water conditions. Features identified by only one map unit contain less than 3 ft (0.9 m) of water at all times and are mapped as surface geometry features. Map units 1-13 describe hydrologic geometry features and map units 15-21 describe surface geometry features. Hydrologic geometry symbols represent class ranges of contact approach angle AA (see Hydrologic Geometry Diagram below), step height SH, position of step base PB referenced to water level, and water depth WD for each bank. Surface geometry symbols represent class ranges of exterior approach angle EA (see Surface Geometry Diagram below), interior approach angle IA, and step height SH for each bank. West bank is the first bank encountered while traversing an area in an easterly direction (i.e. azimuth > 0 to 180 deg) and the east bank is the first bank encountered while traversing an area in a westerly direction (i.e. azimuth > 180 to 360 deg), assuming that the vehicle intersects the feature at a right angle.

Class ranges for each factor are:

Surface Geometry

Terrain Approach Angle (EA & IA)	
Unit	Range
	deg
1	< 100
2	100-< 125
3	125-< 150
4	150-< 165
5	165-< 180
6	180-< 200
7	200-< 210
8	210-< 220
9	≥ 220

Step Height (SH)		
Unit	Range	
	in.	cm
1	0-4	0-10
2	> 4-10	> 10-25
3	> 10-18	> 25-46
4	> 18-30	> 46-76
5	> 30-48	> 76-122
6	> 48-66	> 122-168
7	> 66-84	> 168-213
8	> 84	> 213



Hydrologic Geometry

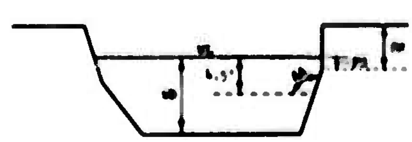
Contact Approach Angle (AA)	
Unit	Range
	deg
1	< 145
2	145-155
3	> 155-165
4	> 165-180

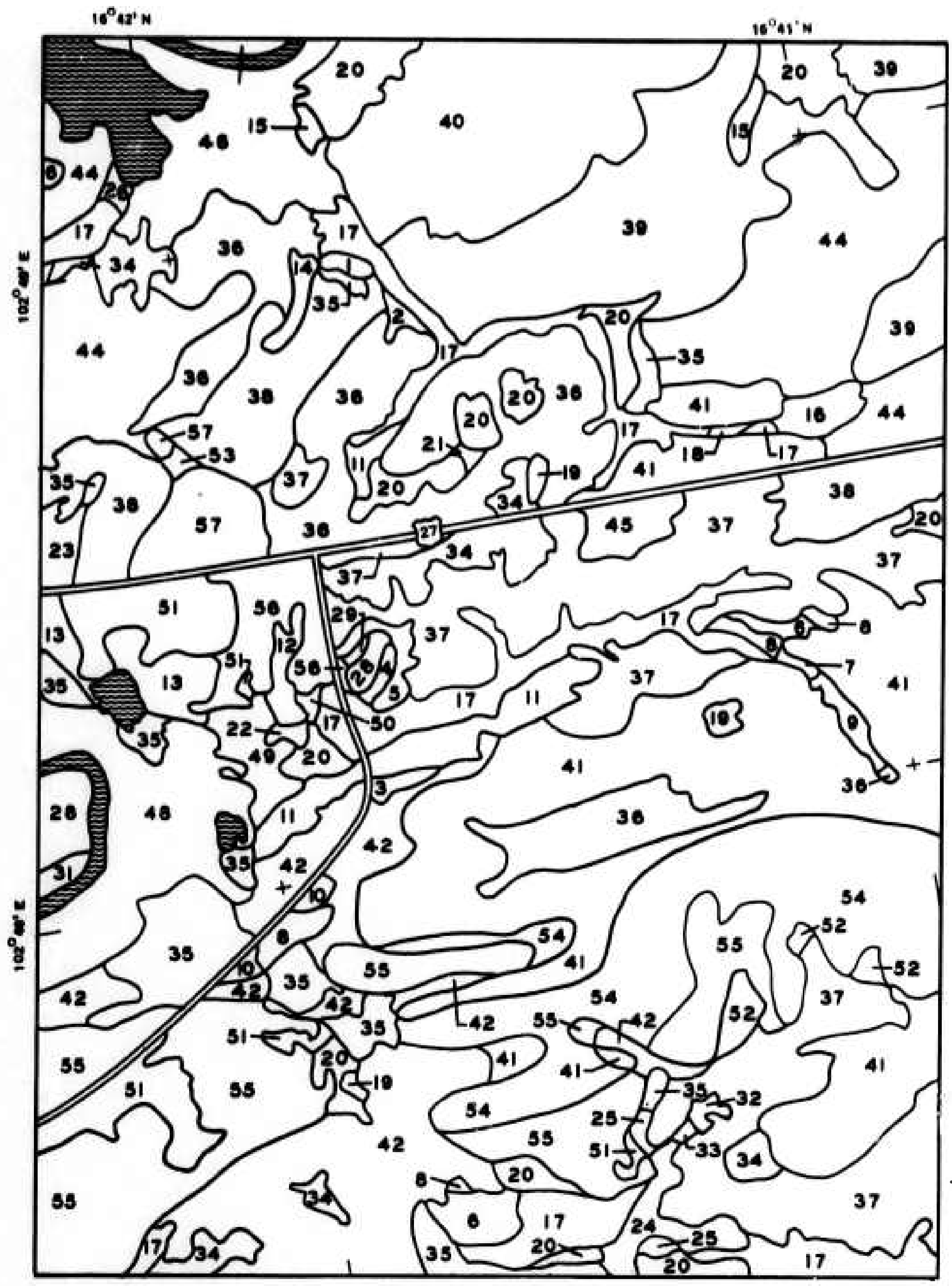
Step Height (SH)		
Unit	Range	
	in.	cm
1	< 12	< 30
2	12-< 24	30-< 61
3	24-< 36	61-< 91
4	36-48	91-122
5	> 48	> 122
0	step absent	step absent

Position of Step Base (PB)		
Unit	Range	
	in.	cm
1	> 48 bwl[1]	> 122 bwl[1]
2	> 30-48 bwl[1]	> 76-122 bwl[1]
3	> 18-30 bwl[1]	> 46-76 bwl[1]
4	1-18 bwl[1]	3-46 bwl[1]
5	at water level	at water level
6	1-12 awl[2]	3-30 awl[2]
7	> 12-30 awl[2]	> 30-76 awl[2]
8	> 30-48 awl[2]	> 76-122 awl[2]
9	> 48 awl[2]	> 122 awl[2]
0	step absent	step absent

Water Depth (WD)		
Unit	Range	
	ft	m
1	3-4.5	0.9-1.4
2	> 4.5	> 1.4

[1] Below water level
[2] Above water level





EXAMPLE OF
FINAL AREAL
FACTOR-COMPLEX MAP

PLATE 7 (1 of 2 sheets)

LEGEND

Unit	Surface Geometry* SL	OS	AA	SH	Surface Composition**	Vegetation† Spacing of Stems ≤ the Specified Diameter 2 in. (5 cm)	5 in. (13 cm)	9 in. (23 cm)	50 in. (127 cm)	Spacing of Stems ≥ the Specified Diameter 1 in. (3 cm)	3 in. (8 cm)	6 in. (15 cm)	10 in. (25 cm)
1	1	3	2/3	3/4	1	4	4	4	4	4	1	1	1
2	1	3	2/3	3/4	2	4	4	4	4	4	1	1	1
3	1	3	2/3	3/5	2	4	4	4	4	4	1	1	1
4	1	3	3/2	4/3	1	4	4	4	4	4	1	1	1
5	1	3	3/2	4/3	2	4	4	4	4	4	1	1	1
6	1	3	3/3	3/3	1	4	4	4	4	4	1	1	1
7	1	3	3/3	3/3	1	2	2	2	2	2	2	1	1
8	1	3	3/3	3/3	2	4	4	4	4	4	1	1	1
9	1	3	3/3	3/3	2	2	2	2	2	2	2	1	1
10	1	3	3/3	3/3	2	1	2	2	2	2	2	2	1
11	1	3	3/3	3/4	2	4	4	4	4	4	1	1	1
12	1	3	3/3	4/3	1	4	4	4	4	4	1	1	1
13	1	3	3/3	4/3	2	4	4	4	4	4	1	1	1
14	1	4	2/3	3/4	1	4	4	4	4	4	1	1	1
15	1	4	2/3	3/4	2	4	4	4	4	4	1	1	1
16	1	4	3/2	4/3	1	4	4	4	4	4	1	1	1
17	1	4	3/3	3/3	1	4	4	4	4	4	1	1	1
18	1	4	3/3	3/3	1	2	2	2	2	2	2	2	1
19	1	4	3/3	3/3	2	1	1	1	1	1	1	1	1
20	1	4	3/3	3/3	2	4	4	4	4	4	1	1	1
21	1	4	3/3	3/3	2	2	2	2	2	2	2	1	1
22	1	4	3/3	3/3	3	4	4	4	4	4	1	1	1
23	1	4	3/3	3/4	2	4	4	4	4	4	1	1	1
24	1	5	3/3	3/3	1	4	4	4	4	4	1	1	1
25	1	5	3/3	3/3	2	4	4	4	4	4	1	1	1
26	1	5	3/5	1/1	1	4	4	4	4	4	1	1	1
27	1	5	5/5	1/1	2	1	1	1	1	1	1	1	1
28	1	5	5/5	1/1	2	4	4	4	4	4	1	1	1
29	1	5	5/5	1/1	2	1	2	2	2	2	2	1	1
30	1	5	5/5	1/1	2	1	2	2	2	2	2	2	1
31	1	5	5/5	1/1	2	4	4	4	4	4	2	2	2
32	2	5	5/5	1/1	1	1	1	1	1	1	1	1	1
33	2	5	5/5	1/1	1	1	2	2	2	2	2	1	1
34	2	5	5/5	1/1	2	1	1	1	1	1	1	1	1
35	2	5	5/5	1/1	2	4	4	4	4	4	1	1	1
36	2	5	5/5	1/1	2	2	2	2	2	2	2	1	1
37	2	5	5/5	1/1	2	1	2	2	2	2	2	1	1
38	2	5	5/5	1/1	2	2	3	3	3	3	2	1	1
39	2	5	5/5	1/1	2	2	2	3	3	3	2	1	1
40	2	5	5/5	1/1	2	3	4	4	4	4	2	1	1
41	2	5	5/5	1/1	2	2	2	2	2	2	2	2	1
42	2	5	5/5	1/1	2	1	2	2	2	2	2	2	1
43	2	5	5/5	1/1	2	1	1	2	2	2	2	2	1
44	2	5	5/5	1/1	2	3	3	3	3	3	2	2	1
45	2	5	5/5	1/1	2	2	3	3	3	3	2	2	1
46	2	5	5/5	1/1	2	4	4	4	4	4	2	2	1
47	2	5	5/5	1/1	2	4	4	4	4	4	3	2	1
48	2	5	5/5	1/1	2	4	4	4	4	4	2	2	2
49	2	5	5/5	1/1	3	4	4	4	4	4	1	1	1
50	3	5	5/5	1/1	1	4	4	4	4	4	1	1	1

Unit	Surface Geometry* SL	OS	AA	SH	Surface Composition**	Spacing of Stem[s ...] Specified Dia[meter] 2 in. (5 cm)	5 in. (13 cm)
51	3	5	5/5	1/1	2	4	4
52	3	5	5/5	1/1	2	1	2
53	3	5	5/5	1/1	2	2	3
54	3	5	5/5	1/1	2	2	2
55	3	5	5/5	1/1	2	1	2
56	3	5	5/5	1/1	2	1	1
57	3	5	5/5	1/1	2	3	3

Note: Blank areas are water bodies.
* Under surface geometry each array of four symbols (
(see diagram below), vertical obstacle spacing OS,
tions indicate that duel classes were mapped. The
be encountered while traversing an area in an easte
denominator refers to a westerly direction (i.e. az
intersects the obstacle at a right angle.

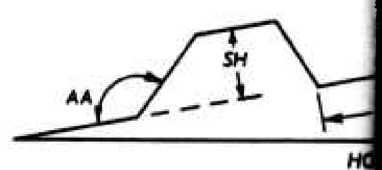
Mapping class ranges for each surface geometry fac

Slope (SL)

Mapping Class	Range deg
1	0-1.5
2	> 1.5-4.5
3	> 4.5-9
4	> 9-18
5	> 18-30
6	> 30-45
7	> 45

Vertical Obstacle Spacing (OS)

Mapping Class	Range ft	m
1	0-7	0-2.
2	> 7-12	> 2.1-3.
3	> 12-50	> 3.7-15
4	> 50-150	> 15.2-45
5	> 150	> 45.7



** Mapping class ranges for each surface composition

Unit	Soil Mass Strength: Maximum Moisture RCI	Minimum Moisture RCI	Maximum Moisture a_{ur} psi	a_{ur} kg/cm^2	α_{ur} deg
1	25-60*	> 100	0-1	0-0.07	>10-2
2	> 60-100*	> 100	0-1	0-0.07	>10-2
3	Complex of > 60-100 and > 100	> 100	0-1	0-0.07	>10-2

a_{ur} Shear strength at zero normal load.

α_{ur} Angle of internal friction.

* Maximum moisture has less than 30 percent p
strengths commonly observed are 60-100 for u

† Mapping class ranges for each vegetation factor-f

Stem

Mapping Class	
1	>
2	> 1
3	>
4	

A.

ion†			
Spacing of Stems ≥ the Specified Diameter			
1 in. (3 cm)	3 in. (8 cm)	6 in. (15 cm)	10 in. (25 cm)
4	1	1	1
4	1	1	1
4	1	1	1
4	1	1	1
4	1	1	1
4	1	1	1
2	2	1	1
4	1	1	1
2	2	1	1
2	2	2	1
4	1	1	1
4	1	1	1
4	1	1	1
4	1	1	1
4	1	1	1
4	1	1	1
4	1	1	1
2	2	2	1
1	1	1	1
4	1	1	1
2	2	1	1
4	1	1	1
4	1	1	1
4	1	1	1
4	1	1	1
4	1	1	1
1	1	1	1
4	1	1	1
2	2	1	1
2	2	2	1
4	2	2	2
1	1	1	1
2	2	1	1
1	1	1	1
4	1	1	1
2	2	1	1
2	2	1	1
3	2	1	1
3	2	1	1
4	2	1	1
2	2	2	1
2	2	2	1
2	2	2	1
3	2	2	1
3	2	2	1
4	2	2	1
4	3	2	1
4	2	2	2
4	1	1	1
4	1	1	1

LEGEND

Unit	Surface Geometry*				Surface Composition**	Vegetation†							
						Spacing of Stems ≤ the Specified Diameter				Spacing of Stems ≥ the Specified Diameter			
	SL	OS	AA	SH		2 in. (5 cm)	5 in. (13 cm)	9 in. (23 cm)	50 in. (127 cm)	1 in. (3 cm)	3 in. (8 cm)	6 in. (15 cm)	10 in. (25 cm)
51	3	5	5/5	1/1	2	4	4	4	4	4	1	1	1
52	3	5	5/5	1/1	2	1	2	2	2	2	2	1	1
53	3	5	5/5	1/1	2	2	3	3	3	3	2	1	1
54	3	5	5/5	1/1	2	2	2	2	2	2	2	2	1
55	3	5	5/5	1/1	2	1	2	2	2	2	2	2	1
56	3	5	5/5	1/1	2	1	1	2	2	2	2	2	1
57	3	5	5/5	1/1	2	3	3	3	3	3	2	2	1

Note: Blank areas are water bodies.

* Under surface geometry each array of four symbols (i.e. 1, 2, 3/3, 3/3) indicates mapping classes of slope SL (see diagram below), vertical obstacle spacing OS, approach angle AA, and step height SH. Fractional designations indicate that duel classes were mapped. The numerator of the fraction indicates class range that will be encountered while traversing an area in an easterly direction (i.e. azimuth from > 0 to 180 deg) and the denominator refers to a westerly direction (i.e. azimuth from > 180 to 360 deg) assuming that the vehicle intersects the obstacle at a right angle.

Mapping class ranges for each surface geometry factor-family unit are:

Slope (SL)

Mapping Class	Range deg
1	0-1.5
2	> 1.5-4.5
3	> 4.5-9
4	> 9-18
5	> 18-30
6	> 30-45
7	> 45

Vertical Obstacle Spacing (OS)

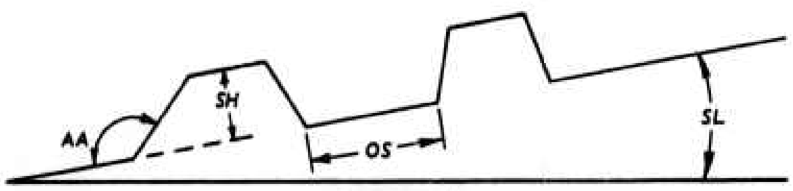
Mapping Class	Range ft	Range m
1	0-7	0-2.1
2	> 7-12	> 2.1-3.7
3	> 12-50	> 3.7-15.2
4	> 50-150	> 15.2-45.7
5	> 150	> 45.7

Approach Angle (AA)

Mapping Class	Range deg
1	< 100
2	100-< 125
3	125-< 150
4	150-< 165
5	165-< 180
6	180-< 200
7	200-< 210
8	210-< 220
9	≥ 220

Step Height (SH)

Mapping Class	Range in.	Range cm
1	0-4	0-10
2	> 4-10	> 10-25
3	> 10-18	> 25-46
4	> 18-30	> 46-76
5	> 30-48	> 76-122
6	> 48-66	> 122-168
7	> 66-84	> 168-213
8	> 84	> 213



HORIZONTAL

** Mapping class ranges for each surface composition factor-family unit are:

Unit	Soil Mass Strength		Soil Surface Strength								
	Maximum Moisture	Minimum Moisture	Maximum Moisture			Minimum Moisture			Conditions Where Maximum a_{ur} Occurs		
			a_{ur}		α_{ur}	a_{ur}		α_{ur}	a_{ur}		α_{ur}
	RCI	RCI	psi	kg/cm^2	deg	psi	kg/cm^2	deg	psi	kg/cm^2	deg
1	25-60*	> 100	0-1	0-0.07	>10-20	0-1	0-0.07	> 20-40	> 2-4	> 0.14-0.28	> 20-40
2	> 60-100*	> 100	0-1	0-0.07	>10-20	0-1	0-0.07	> 20-40	> 1-2	> 0.07-0.14	> 10-20
3	Complex of > 60-100 and > 100	> 100	0-1	0-0.07	>10-20	0-1	0-0.07	> 20-40	Minimum moisture conditions		

a_{ur} Shear strength at zero normal load.

α_{ur} Angle of internal friction.

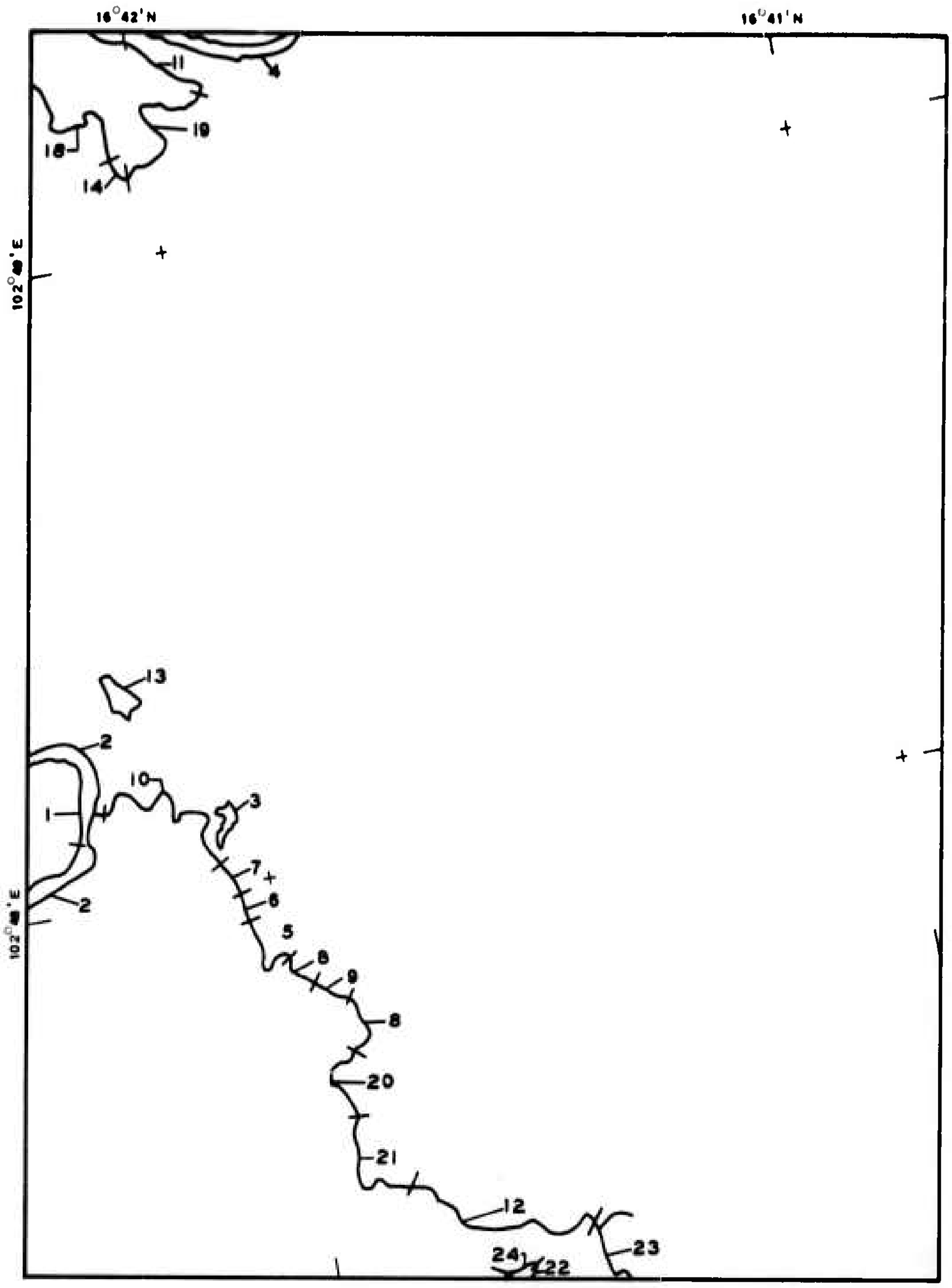
* Maximum moisture has less than 30 percent probability of occurrence during the wet season. Lowest strengths commonly observed are 60-100 for unit 1; more than 100 for unit 2.

† Mapping class ranges for each vegetation factor-family unit are:

Stem Spacing

Mapping Class	Range ft	Range m
1	> 30	> 9.1
2	> 10-30	> 3.0-9.1
3	> 5-10	> 1.5-3.0
4	0-5	0-1.5

B.



EXAMPLE OF
FINAL LINEAR
FACTOR-COMPLEX MAP

PLATE 8 (1 of 2 sheets)

LEGEND

Map Unit	FACTOR FAMILY																											
	Hydrologic Geometry*														Surface Geometry**												Surface Composition†	Vegetation††
	High-Water Conditions							Low-Water Conditions							High-Water Conditions						Low-Water Conditions							
	West Bank			East Bank				West Bank			East Bank				West Bank			East Bank			West Bank			East Bank				
	AA	SH	PS	AA	SH	PS	WD	AA	SH	PS	AA	SH	PS	WD	EA	IA	SH	IA	EA	SH	EA	IA	SH	IA	EA	SH		
1	1	x	x	1	x	x	2	2	5	2	1	x	x	2													2	2
2	1	x	x	1	x	x	2	2	5	2	1	x	x	2													2	15
3	1	x	x	2	x	x	2	3	2	7	3	2	7	1													2	15
4	2	x	x	2	x	x	2	3	4	5	3	4	5	1													2	13
5	2	1	5	2	3	4	1														6	3	5	2	7	5	2	2
6	2	1	5	2	3	4	1														6	3	5	2	7	5	2	9
7	2	1	5	2	3	4	1														6	3	5	2	7	5	2	15
8	2	3	5	2	3	5	1														6	3	5	3	6	5	2	2
9	2	3	5	2	3	5	1														6	3	5	3	6	5	2	9
10	2	3	5	2	3	5	2	2	3	8	2	3	8	1													2	15
11	2	3	5	2	3	5	2	3	3	7	3	3	7	1													2	13
12	2	4	3	2	4	3	1														6	4	5	4	6	5	1	2
13	3	x	x	3	x	x	1														6	5	5	5	6	5	2	2
14	3	x	x	3	x	x	2	3	x	x	3	x	x	1													1	2
15	3	x	x	3	x	x	2	3	x	x	3	x	x	1													2	1
16	3	x	x	3	x	x	2	3	x	x	3	x	x	1													2	2
17	3	x	x	3	x	x	2	3	x	x	3	x	x	1													2	9
18	3	x	x	3	x	x	2	3	x	x	3	x	x	1													2	11
19	3	x	x	3	x	x	2	3	x	x	3	x	x	1													2	13
20	3	4	5	3	4	5	1														7	3	5	3	7	5	2	1
21	3	4	5	3	4	5	1														7	3	5	3	7	5	2	9
22															6	4	4	4	6	4	6	4	4	4	6	4	2	2
23															6	4	5	4	6	5	6	4	5	4	6	5	1	2
24															9	1	6	1	9	6	9	1	6	1	9	6	2	2

Note: Hydrologic geometry symbols represent class ranges of contact approach angle AA (see Hydrologic Geometry Diagram below), step height SH, position of step base PS referenced to water level, and water depth WD for each bank. Surface geometry symbols represent class ranges of exterior approach angle EA (see Surface Geometry Diagram below), interior approach angle IA, and step height SH for each bank. West bank is the first bank encountered while traversing an area in an easterly direction (i.e. azimuth > 0 to 180 deg) and the east bank is the first bank encountered while traversing an area in a westerly direction (i.e. azimuth > 180 to 300 deg), assuming that the vehicle intersects the feature at a right angle.

* Mapping class ranges for each hydrologic factor-family unit are:

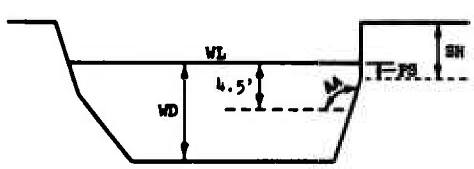
Hydrologic Geometry

Contact Approach Angle (AA)	
Unit	Range, deg
1	< 145
2	145-155
3	> 155-165
4	> 165-180

Step Height (SH)		
Unit	Range, in.	Range, cm
1	< 12	<30
2	12-< 24	30-< 61
3	24-< 36	61-< 91
4	36-48	91-122
5	> 48	> 122
x	step absent	step absent

Water Depth (WD)		
Unit	Range, ft	Range, m
1	3-4.5	0.9-1.4
2	> 4.5	> 1.4

Position of Step Base (PS)		
Unit	Range, in.	Range, cm
1	> 48 bwl[1]	> 122 bwl[1]
2	> 36-48 bwl[1]	> 91-122 bwl[1]
3	> 18-36 bwl[1]	> 46-91 bwl[1]
4	1-18 bwl[1]	3-46 bwl[1]
5	at water level	at water level
6	1-12 awl[2]	3-30 awl[2]
7	> 12-30 awl[2]	> 30-76 awl[2]
8	> 30-48 awl[2]	> 76-122 awl[2]
9	> 48 awl[2]	> 122 awl[2]
x	step absent	step absent



[1]Below water level
[2]Above water level

† Mapping class ranges f

	Soil Mass Strength	
	Maximum Moisture	Minimum Moisture
Unit	RCI	RCI
1	25-60*	> 100
2	> 60-100*	> 100

a_{ur} Shear strength a

α_{ur} Angle of internal

* Maximum moisture
Lowest strengths c

†† Mapping class ranges f

	Spacing Class Rang		
	≤		
Unit	2 in. (5 cm)	5 in. (13 cm)	9 (23
1	> 30	> 30	>
2	0-5	0-5	0-
9	> 30	> 10-30	> 10-
11	> 5-10	> 5-10	> 5-
13	0-5	0-5	0-
15	0-5	0-5	0-

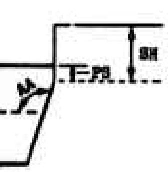
A.

LEGEND

Surface Geometry**										Surface Composition†	Vegetation††
...ater Conditions				Low-Water Conditions							
...nk	East Bank			West Bank			East Bank				
SH	IA	EA	SH	EA	IA	SH	IA	EA	SH		
										2	2
										2	15
										2	15
										2	13
				6	3	5	2	7	5	2	2
				6	3	5	2	7	5	2	9
				6	3	5	2	7	5	2	15
				6	3	5	3	6	5	2	2
				6	3	5	3	6	5	2	9
										2	15
										2	13
				6	4	5	4	6	5	1	2
				6	5	5	5	6	5	2	2
										1	2
										2	1
										2	2
										2	9
										2	11
										2	13
				7	3	5	3	7	5	2	1
				7	3	5	3	7	5	2	9
4	4	6	4	6	4	4	4	6	4	2	2
5	4	6	5	6	4	5	4	6	5	1	2
6	1	9	6	9	1	6	1	9	6	2	2

e AA (see
referenced to water
class ranges of
proach angle IA, and
traversing an area
the first bank en-
80 to 300 deg),

r Depth (WD)	
Range	
ft	m
3-4.5	0.9-1.4
> 4.5	> 1.4

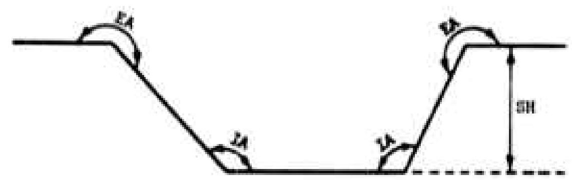


** Mapping class ranges for each surface geometry factor-family unit are:

Surface Geometry

Terrain Approach Angle (EA & IA)	
Unit	Range deg
1	< 100
2	100-< 125
3	125-< 150
4	150-< 165
5	165-< 180
6	180-< 200
7	200-< 210
8	210-< 220
9	≥ 220

Step Height (SH)		
Unit	Range	
	in.	cm
1	0-4	0-10
2	> 4-10	> 10-25
3	> 10-18	> 25-46
4	> 18-30	> 46-76
5	> 30-48	> 76-122
6	> 48-66	> 122-168
7	> 66-84	> 168-213
8	> 84	> 213



† Mapping class ranges for each surface composition factor-family unit are:

	Soil Mass Strength		Soil Surface Strength								
	Maximum Moisture	Minimum Moisture	Maximum Moisture			Minimum Moisture			Conditions Where Maximum a_{ur} Occurs		
			a_{ur}		α_{ur}	a_{ur}		α_{ur}	a_{ur}		α_{ur}
Unit	RCI	RCI	psi	kg/cm^2	deg	psi	kg/cm^2	deg	psi	kg/cm^2	deg
1	25-60*	> 100	0-1	0-0.07	> 10-20	0-1	0-0.07	> 20-40	> 2-4	> 0.14-0.28	> 20-40
2	> 60-100*	> 100	0-1	0-0.07	> 10-20	0-1	0-0.07	> 20-40	> 1-2	> 0.07-0.14	> 10-20

a_{ur} Shear strength at zero normal load.

α_{ur} Angle of internal friction.

* Maximum moisture has less than 30 percent probability of occurrence during the wet season. Lowest strengths commonly observed are 60-100 for unit 1; more than 100 for unit 2.

†† Mapping class ranges for each vegetation factor-family unit are:

	Spacing Class Ranges for Stems ≤ and ≥ the Specified Diameter							
	≤				≥			
Unit	2 in. (5 cm)	5 in. (13 cm)	9 in. (23 cm)	50 in. (127 cm)	1 in. (3 cm)	3 in. (8 cm)	6 in. (15 cm)	10 in. (25 cm)
1	> 30	> 30	> 30	> 30	> 30	> 30	> 30	> 30
2	0-5	0-5	0-5	0-5	0-5	> 30	> 30	> 30
9	> 30	> 10-30	> 10-30	> 10-30	> 10-30	> 10-30	> 10-30	> 30
11	> 5-10	> 5-10	> 5-10	> 5-10	> 5-10	> 10-30	> 10-30	> 30
13	0-5	0-5	0-5	0-5	0-5	> 10-30	> 10-30	> 30
15	0-5	0-5	0-5	0-5	0-5	> 10-30	> 10-30	> 10-30

B.

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) U. S. Army Engineer Waterways Experiment Station Vicksburg, Mississippi	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

3. REPORT TITLE
MOBILITY ENVIRONMENTAL RESEARCH STUDY; A QUANTITATIVE METHOD FOR DESCRIBING TERRAIN FOR GROUND MOBILITY; SUMMARY

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
Volume I of an eight-volume report

5. AUTHOR(S) (First name, middle initial, last name)
John H. Shamburger
Warren E. Grabau

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1968	50	3

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S) Technical Report No. 3-726
b. PROJECT NO.	
c. Order No. 400	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT
This document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of U. S. Army Materiel Command.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Advanced Research Projects Agency; Service Agency; U. S. Army Materiel Command, Washington, D. C.

13. ABSTRACT
Knowledge of exact terrain conditions and vehicle characteristics is a prerequisite for predicting vehicle performance across terrain. The development at the U. S. Army Engineer Waterways Experiment Station of an analytical model for predicting the cross-country speed of ground-contact military vehicles resulted in the isolation of those terrain factors that significantly affect the locomotion of ground-contact vehicles. Those factors are encompassed in four factor families--surface composition, surface geometry, vegetation, and hydrologic geometry. Since a condition of this study was to establish the effects of terrain on vehicle locomotion in Southeast Asia, six areas in Thailand were selected for detailed study. These areas are in the vicinities of Nakhon Sawan, Lop Buri, Chiang Mai, Pran Buri, Khon Kaen, and Chanthaburi. This report is presented in eight volumes. This volume is a summary and discusses in general terms the procedures that were used to acquire the necessary quantitative terrain information and the techniques that were employed to adapt these data to displays that meet the specific requirements of cross-country locomotion analysis. Data collection, reduction and analysis procedures, and techniques for mapping the specific factors of each factor family are presented in Volume II (Surface Composition), Volume III (Surface Geometry), Volume IV (Vegetation), and Volume V (Hydrologic Geometry). Data summaries are included as appendixes to the appropriate volumes. Air-photo interpretation techniques used to identify air-photo patterns of terrain features are presented in Volume VI. The method used to synthesize the factor-family maps into factor-complex maps for mobility purposes is presented in Volume VII. Map sets for each of the four factor families for the six study areas are presented in Volume VIII.

DD FORM 1 NOV 65 1473 REPLACES DD FORM 1473, 1 JAN 64, WHICH IS OBSOLETE FOR ARMY USE.

Unclassified
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Cross-country terrain						
Environmental studies						
Mobility						
Terrain						
Thailand						
Vehicles						

Unclassified

Security Classification